

1.2. Semiconductors,
Conductors, &
Insulators.

Energy Band Theory. ①

:- In terms of Their electrical properties, materials can be classified into three groups: Conductors, Semiconductors & insulators. On the basis of band theory of solids, the distinction between metals, semiconductors and insulators can be explained. First, it should be emphasized that empty energy bands, which do not contain electrons, do not contribute to the electrical conductivity of a material; whereas, although completely filled bands contain electrons, they do not contribute to the electrical conductivity, since the carriers are unable to gain energy (when an electric field is applied) due to the fact that all the energy levels are occupied. In comparison, the partially filled bands contain both the electrons and unoccupied energy levels at higher energies. The latter allow carriers to gain energy in the presence of an applied electric

② Basic Electronics For MSc. Physics Lecture 1.

field, and thus, carriers in partially filled band can contribute to the electrical conductivity of the material. In the case of metals, the electronic band structure results in incomplete filling of the highest occupied energy band. If an electron acquires enough additional energy from an external source, it leaves the valence shell and becomes a free electron and exists in what is known as the 'conduction band'.

The difference in the energy between the valence band and the conduction band is called the 'energy gap'. This is the amount of energy that a valence electron must have in order to jump from the valence band to the conduction band. Once in the conduction band the electron is free to move throughout the material and is not tied to any given atom.

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Figure 1 shows energy diagrams for the three types of materials.

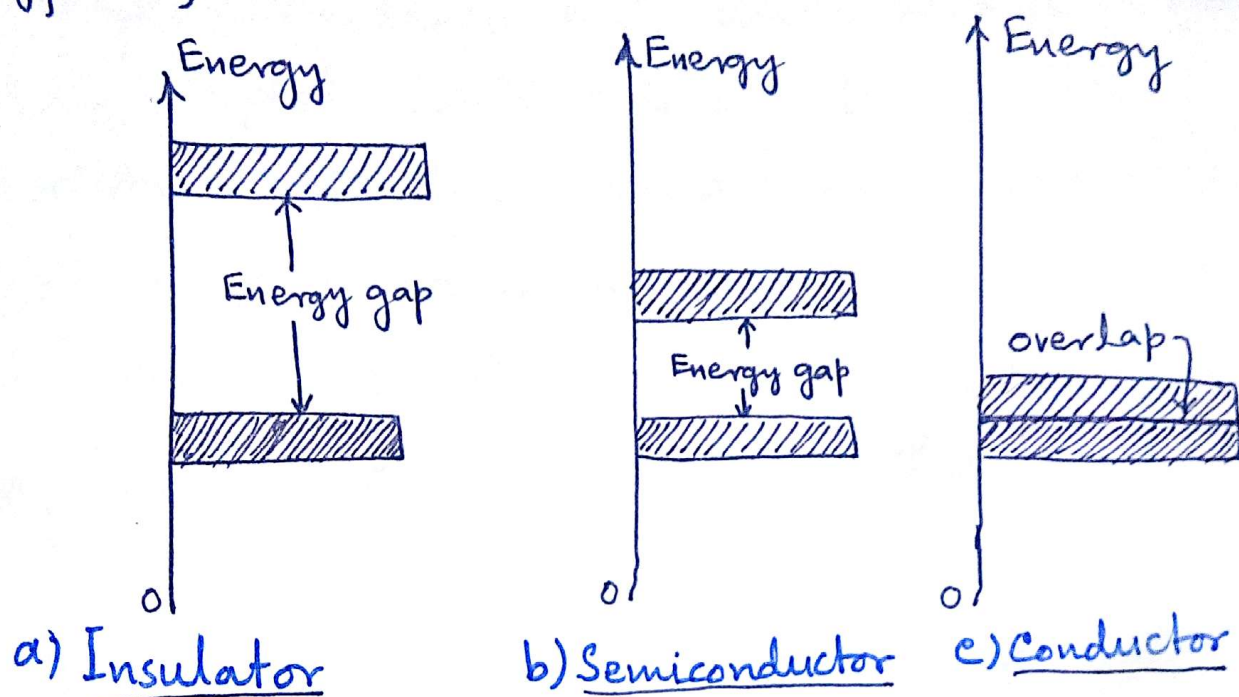


Fig. 1. Energy diagrams for the Three types of materials.

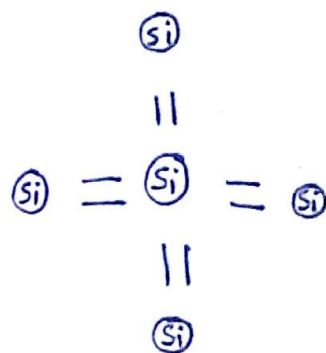
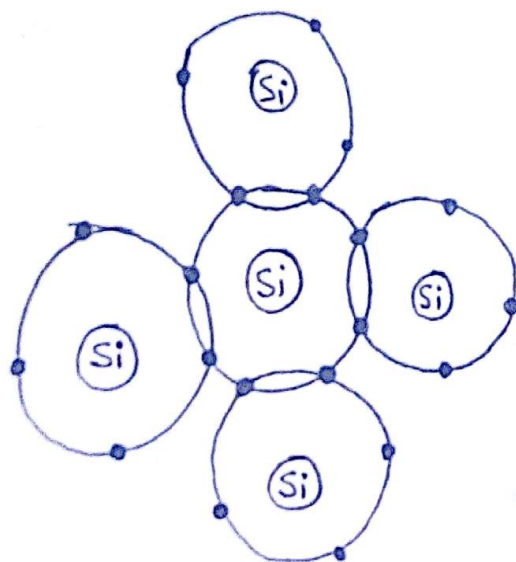
Notice in part (a) that insulators have a very wide energy gap. Valence electrons cannot jump into the conduction band except under breakdown conditions where extremely high voltages are applied across the material. In Fig. 1(b), note that semiconductors have a much narrower energy gap. This gap permits some valence electrons to jump into the conduction band and become free electrons. The energy band in conductors overlap hence there are large number of free electrons.

§2.3 Silicon Crystals.

① Basic Electronics For MSc. Physics Lecture 2

② When silicon atoms combine to form solid, they arrange themselves into an orderly pattern called crystal. Each silicon atom shares its electrons with four neighbouring atoms in such a way as to have eight electrons in its valence orbit. For instance, Fig. 4 shows a central atom with four neighbours.

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b) Covalent bond.

Fig. 4 (a) Atom in crystal has Four neighbours.

§§. Covalent Bond:- Each neighbouring atom shares an electron with the central atom. In this way, the central atom has four additional electrons, giving it a total of eight electrons in the valence orbit. The electrons no longer belong to any single atom.

(2) Basic Electronics Lecture 2 For MSc. Physics

Each central atom and its neighbours share electrons. The same idea is true for all the other silicon atoms. In other words every atom inside a silicon crystal has four neighbours.

Since each shared electron in Fig. 1 is being pulled in opposite directions, the electrons become a bond between the opposite cores. This type of chemical bond is called a covalent bond.

§§ Valence Saturation:- Each atom in a silicon crystal has eight electrons in its valence orbit. These eight electrons produce a chemical stability that results in a solid piece of silicon material. When the valence orbit has eight electrons, it is saturated because no more electrons can fit into this orbit. Stated as a law:

Valence saturation : $n = 8$

In other words, The valence orbit can hold no more than eight electrons. A silicon crystal is perfect insulator at about 25°C .

§§. Holes.

③ Basic Electronics For MSc. Physics Lecture 2

The ambient temperature is the temperature of the surrounding air. When the ambient temperature is above absolute zero, the heat energy in the air causes the atoms in the silicon crystal to vibrate. The higher the ambient temperature, the stronger the mechanical vibrations become.

In silicon crystal, the vibrations of the atoms can occasionally dislodge an electron from the valence orbit. When this happens, the released electron gains enough energy to go into larger orbits. In this larger orbit, the electron is a free electron. The departure of the electron creates a vacance called a hole. This hole behaves like a positive charge because the loss of the electron produces a positive ion. The hole will attract and capture any electron in the immediate vicinity. The existence of holes is the critical difference between conductors and semiconductors. To increase the number of holes the crystal is doped.

§§ Recombination & Lifetime (4) Basic Electronics For MSc. Physics Lecture 2.

In a pure silicon crystal, Thermal energy creates an equal number of free electrons and holes. The free electrons move randomly throughout the crystal. Occasionally, a free electron will approach a hole, feel its attraction and fall into it.

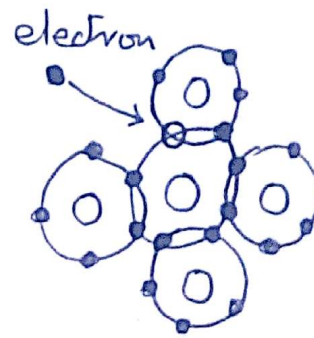
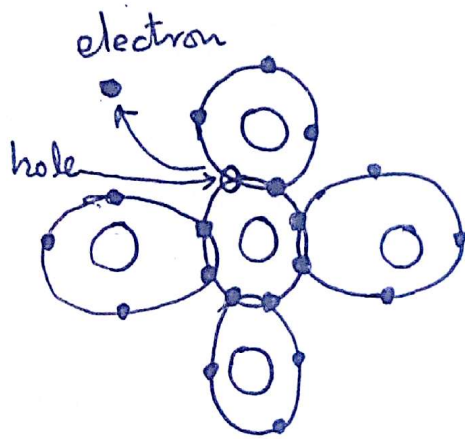


Fig. 2. a) An electron-hole pair is produced.

b) Recombination.

Recombination is The merging of a free electron and a hole, as shown in Fig. 2. (b).

The amount of time between the creation and disappearance of a free electron is called The life time. It varies from a few nanoseconds to several microseconds, depending on how perfect the crystal is and other factors.

§ 3.9 DC Resistance of a diode: If we take the ratio of the total diode voltage to total diode current, we get the dc resistance of the diode. In forward direction, this dc resistance is symbolized by R_F ; in reverse direction it is R_R .

Forward Resistance.. Because diode is a non-linear device its dc resistance varies with the current through it. For example, here are some pairs of forward current and voltage for a 1N914: 10mA at 0.65V, 30mA at 0.75V and 50mA at 0.85V. At the first point the dc resistance is:

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$$R_F = \frac{0.65V}{10mA} = 65 \Omega$$

At the second point:

$$R_F = \frac{0.75V}{30mA} = 25 \Omega$$

& At the third point $R_F = \frac{0.85V}{50mA} = 17 \Omega$

Notice how the dc resistance decreases as the current increases. In any case the forward resistance is low as compared to the reverse resistance.

Reverse Resistance.. Similarly, here are two sets of reverse current and voltage, for 1N914: 25nA at 20V; 5μA at 75V. at the first point, The dc resistance is:

$$R_R = \frac{20V}{25nA} = 800 M\Omega$$

At the second point: $R_R = \frac{75V}{5\mu A} = 15 M\Omega$

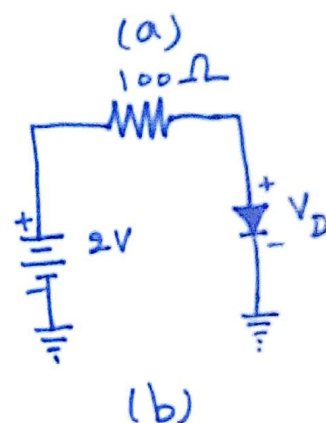
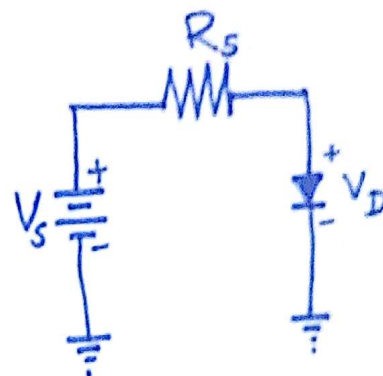
§ 3.10 Load Lines. Load line is a tool used to find the exact value of diode current and voltage

Equation for the Load Line.

To find the exact diode current and voltage in Fig I.(a), the current through the resistor is,

$$I_D = \frac{V_S - V_D}{R_S} \quad \text{--- (I)}$$

Because of the series circuit this current is the same through the diode.



An. example.:- If the source voltage is 2V and the resistance is 100Ω , as shown in Fig. I.(b). Then Eqn. I

Fig. I. Load-line analysis.

becomes

$$I_D = \frac{2 - V_D}{100} \quad \text{--- (II)}$$

Eqn. (II) is a linear relationship between current and voltage. If we plot this equation, we get a straight line. For instance, let V_D equal zero,

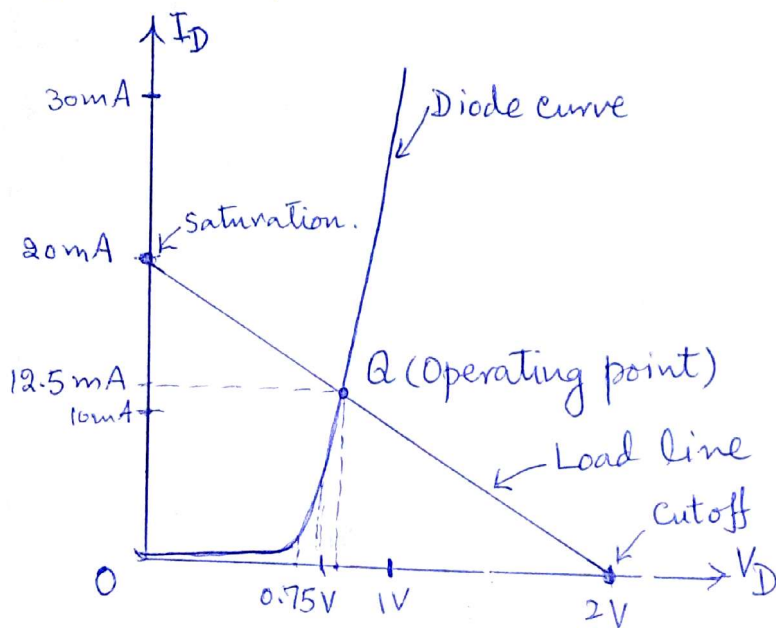
Then:
$$I_D = \frac{2V - 0V}{100\Omega} = 20\text{mA}$$

Plotting This point ($I_D = 20\text{mA}$, $V_D = 0$) gives the point on the vertical axis of Fig(II). This point is called saturation because it represents maximum current with 2V across 100Ω .

Now, let $V_D = 2V$. Then Eqn. (II) gives:

$$I_D = \frac{2V - 2V}{100\Omega} = 0A.$$

When we plot this point ($I_D = 0, V_D = 2V$) we get the point shown on the horizontal axis (Fig. II). This point is called cutoff because it represents minimum or zero current. the straight line joining these points is called the load line.



Fig(II). Diode curve, load line, Q point.

the Q-point:- Fig. II shows the load line and a diode curve. The point of intersection, known as the Q point, represents a simultaneous solution between the diode curve and the load line. In other words, the Q-point is the only point on the graph that works for both the diode & the circuit. By reading the coordinates of the Q point, we get a current of 12.5 mA & a diode voltage of 0.75V. In the present discussion, Q is an abbreviation for quiescent, which means 'at rest'.

Note that the equation for load line, $I_D = -\frac{V_D}{R} + \frac{V_s}{R}$ is of the form of $y = mx + c$ (the Eqn of straight line where m is the slope of the line).

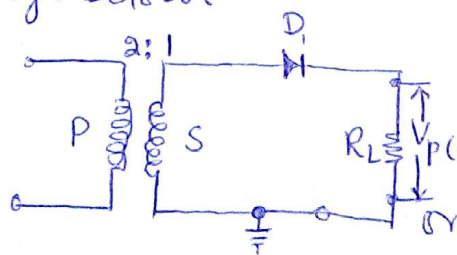
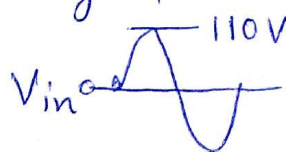
By:

The significance of the dc load line is that every possible combination of the current I & voltage V in the circuit is a point that lies somewhere on the line. Given a particular diode, whose characteristic I - V curve we happen to have, our object is to find the current-voltage combination that results when that diode is inserted in the circuit. We can find that point by plotting the dc load line on the same I - V axes that contain the diode's characteristic curve. The intersection of the dc load line and the characteristic curve gives us the actual diode current and voltage that results when the diode is used in the circuit. What we have accomplished, in effect, is a graphical solution of the two simultaneous equations

$$I = -(1/R)V + E/R \quad (\text{the load line})$$

$$\& \quad I = I_s (e^{V/nV_T} - 1) \quad (\text{the characteristic curve})$$

Example:- Determine the peak value of the output voltage for the Fig. below.



$$V_{p(\text{prim})} = 110V$$

$$N_s/N_p = \frac{1}{2} = 0.5$$

$$V_s(\text{secondary}) = 0.5 V_{p(\text{prim})}$$

$$V_s(\text{secondary}) = 0.5 \times 110 = 55V$$

The peak rectified output voltage is

$$V_{p(\text{out})} = V_{p(\text{sec})} - 0.7V = 55V - 0.7V = 54.3V$$

Example 4.5, PP-104

Calculate the peak input & output voltages in the Fig. below.

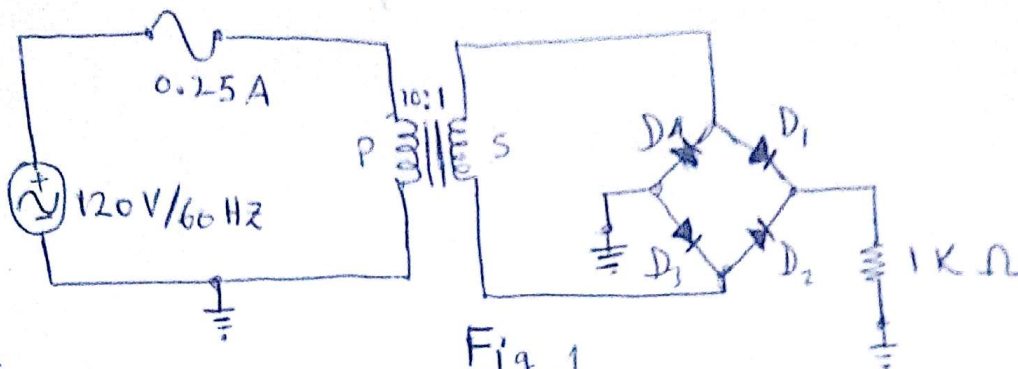


Fig. 1

Solution:- The peak primary voltage is:

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$$V_{P(1)} = \frac{V_{rms}}{0.707} = \frac{120V}{0.707}$$

$$V_{P(1)} = 170V \text{ (Primary)}$$

Because of the 10:1 Step-down transformer, the peak secondary voltage is:

$$\begin{aligned} V_{P(2)} &= \frac{V_{P(1)}}{N_1/N_2} = \frac{170V}{10} \\ \text{or } V_{P(2)} &= 17V \text{ (Secondary)} \end{aligned}$$

To a second approximation:

$$\begin{aligned} V_{P(out)} &= 17 - 1.4V \\ &= 15.6V \end{aligned}$$

If we check these values experimentally using voltmeter or an oscilloscope we see that both input and output readings are approximately the same as the theoretical values.

§ 4.5 The Choke-input Filter. The filter shown in Fig. 2. is called a choke-input filter.

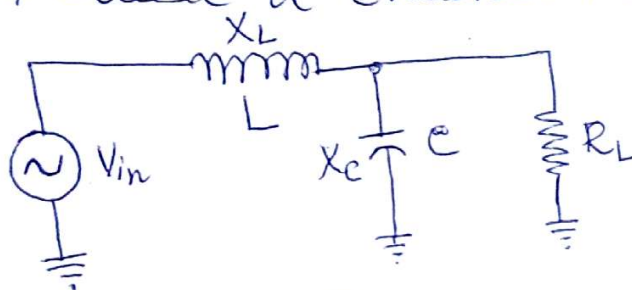


Fig: 2

The ac current in each component depends on the inductive reactance, capacitive reactance and the resistance. the inductor has a reactance given by $X_L = 2\pi fL$ — (I)

And the capacitor has reactance given by $X_C = \frac{1}{2\pi fC}$ — (II)

The choke or inductor has the primary characteristic of opposing a change in current. Because of this a choke-input filter ideally reduces the ac current in the load resistor to zero. The capacitor provides an easy path to a.c. and hence short circuit the ac to ground.

The circuit acts like a reactive voltage divider. When X_L is much greater than X_C , almost all the ac voltage is dropped across the choke. In this case, the ac output voltage equals:

$$V_{out} = \frac{X_C}{X_L} V_{in}$$

For instance if $X_L = 10k\Omega$, $X_C = 100\Omega$ & $V_{in} = 15V$
The ac output voltage is $V_{out} \approx \frac{100\Omega}{10k\Omega} 15V = 0.15V$
Note that almost all the ac is blocked by the filter.

§ 4.6: The Capacitor-Input Filter:-

The capacitor-input filter produces a dc output voltage equal to the peak value of the rectified voltage. This type of filter is the most widely used in power supplies.

Fig-3 shows an ac source, a diode and a capacitor.

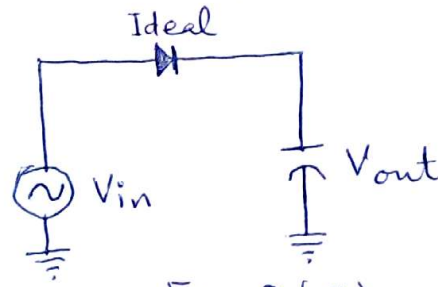
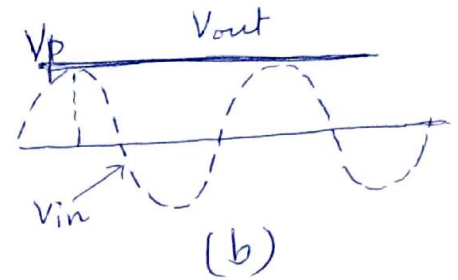


Fig. 3(a)



Initially, the capacitor is uncharged. During the first quarter cycle of Fig-3(b) the diode is forward biased, the capacitor charges and its voltage becomes equal to the source voltage. The charging continues until the input reaches its maximum value. At this point the capacitor voltage equals V_p . During the remaining cycle, the capacitor stays fully charged and the diode remains open.

Full-Wave Filtering. If we connect a full-wave or bridge rectifier to a capacitor input filter, the peak-to-peak ripple is cut in half. When a full wave is applied to an RC circuit, the capacitor discharges for only half as long, therefore the peak-to-peak ripple is half the size it would be with a half wave rectifier.

The ripple-formula.

The ripple formula used to estimate the peak to peak ripple out of any capacitor-input filter is given by

$$V_R = \frac{I}{fC} \quad \text{--- (1)}$$

Where V_R is peak to peak ripple voltage

I is the dc load current

f is the ripple frequency

C is the capacitance.

This is an approximation, not an exact derivation.

If the dc load current is 10 mA and the capacitance is 20 μ F, the ripple with a bridge rectifier and a capacitor-input filter is:

$$V_R = \frac{10 \text{ mA}}{(120 \text{ Hz})(20 \mu\text{F})}$$

$$V_R = 0.417 V_{PP}$$

This formula works for Half-wave or full-wave voltage. For half-wave the frequency is 60 Hz. for full wave 120 Hz.

Assignment: 1

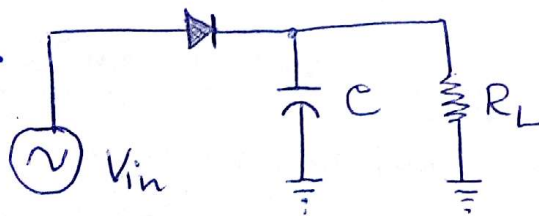
Example 4.6

Example 4.7

Example 4.8

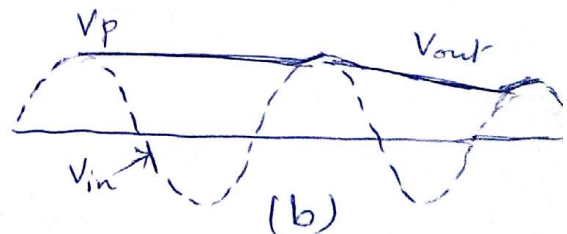
Example 4.9

Example 4.11



(a)

Capacitor input-filter. Fig. 4



(b)



(c) Full wave output has less ripples

§ 4.10 :- Clippers and Clampers.

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The diodes used in low frequency power supplies are rectifier diodes. These diodes are optimized for use at 60 Hz and have power ratings greater than 0.5 W. A typical rectifier diode has a forward current rating in amperes. There are other diodes optimized for use at higher frequencies and have power rating less than 0.5 W. This typical small-signal diode has a current rating in milliamperes.

The positive clipper.

* A clipper is a circuit that removes either positive or negative parts of a wave form. This kind of processing is useful for signal shaping.

Fig. I. shows a diode limiter circuit (clipper) that limits or clips the positive part of the input voltage.

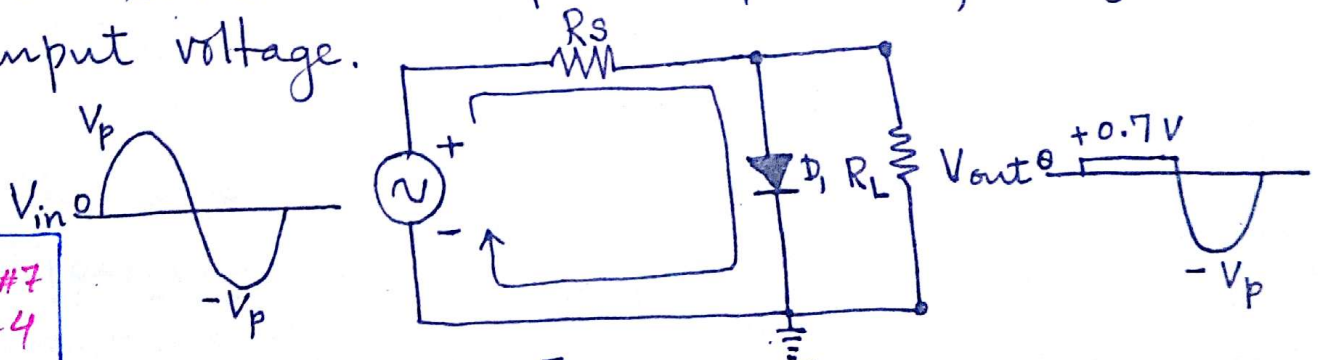


Fig. I. The Positive Clipper.

The negative clipper.

Fig. II shows a diode limiter circuit (negative clipper) that limits or clips the negative part of the input voltage.

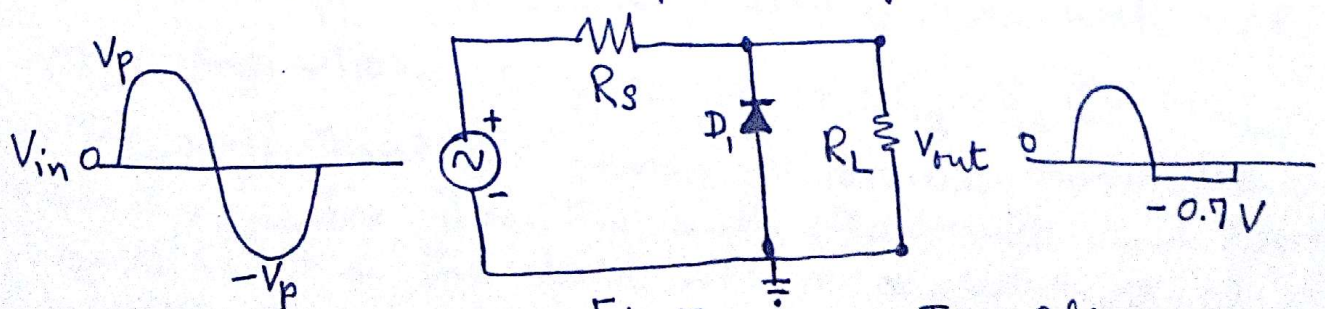


Fig. II. The negative Clipper.

Working of a clipper.

See Fig. I (Positive clipper). During positive half cycle the diode turns on and looks like a short across output terminals. Ideally, the output voltage is zero. On the negative half cycle, the diode is open, in this case a negative half-cycle appears across output.

To a second approximation, The diode voltage is 0.7 volts when conducting, therefore The clipping level is not zero but 0.7V.

Small signal diodes have a smaller junction area than rectifier diodes because they are optimized to work at higher frequencies. As a result they have more bulk resistance. The data sheet of a small-signal diode like the 1N914 lists a forward current of 10mA at 1V. Therefore the bulk resistance is:

$$R_B = \frac{1V - 0.7V}{10mA} = 30\Omega$$

The bulk resistance is important because the clipper will not work properly, unless the series resistance R_s is much greater than the bulk resistance. Furthermore, the clipper won't work properly unless the series resistance R_s is much smaller than the load resistance. For a clipper to work properly, we will use this definition: Stiff clipper: $100 R_B < R_s < 0.01 R_L$

This says that the series resistance must be 100 times greater than the bulk resistance and 100 times smaller than the load resistance. When a clipper satisfies these conditions, we call it a stiff clipper.

Biased Clippers:-

The reference level (clipping level) of a positive clipper is ideally zero or 0.7 to a second approx. we can change this reference level by applying an external voltage (bias) as shown in Fig III.

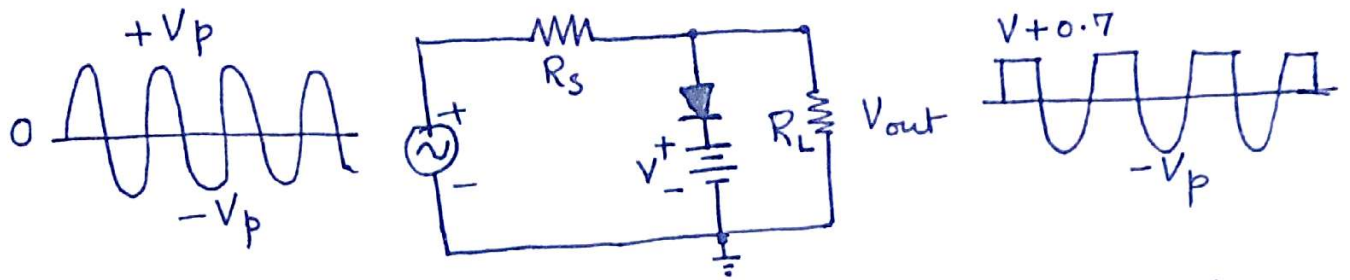


Fig III Biased positive clipper.

In this case the diode will start conducting when the input voltage is greater than $V + 0.7V$.

Fig. IV shows how to bias a negative clipper. Notice that the diode and the battery have been reversed. Because of this, the reference level changes to $-V - 0.7V$. The output waveform is negatively clipped at the bias level.

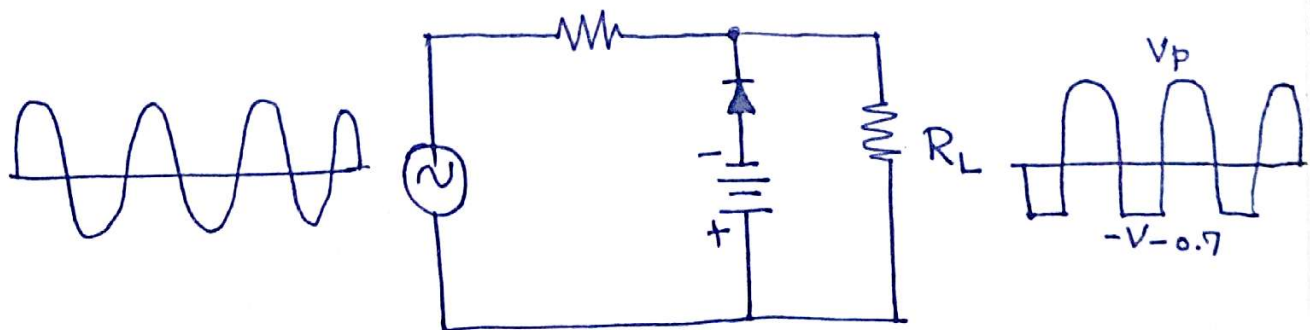
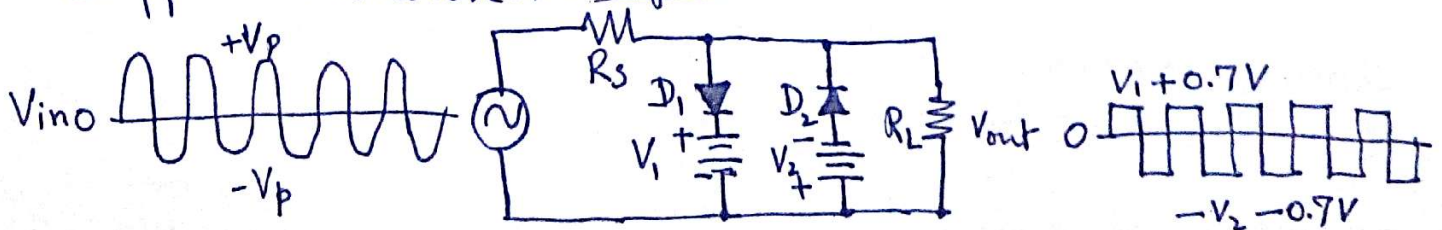


Fig (IV) Biased negative clipper.

Combination Clipper:- we can combine the two biased clipper as shown in Fig(V)



§ 4.11. Clampers:-

A clamper adds a dc voltage to the signal. Fig. 1 shows the basic idea for a positive clamper.

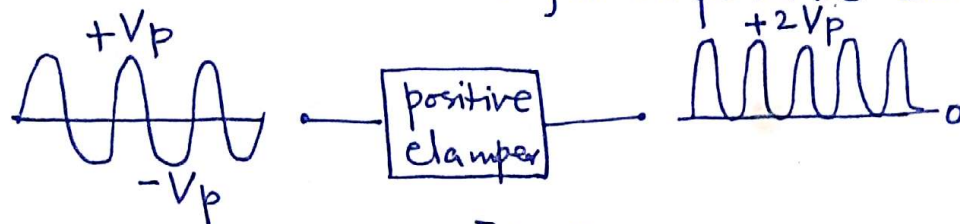


Fig. 1

Clampers are sometimes known as dc restorers.

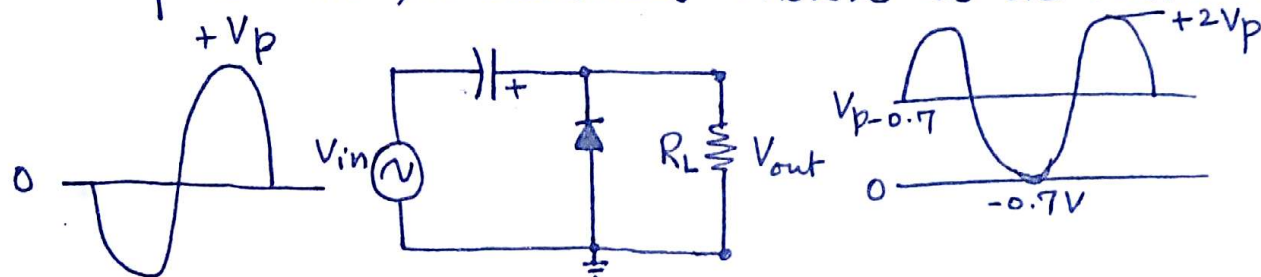


Fig. 2

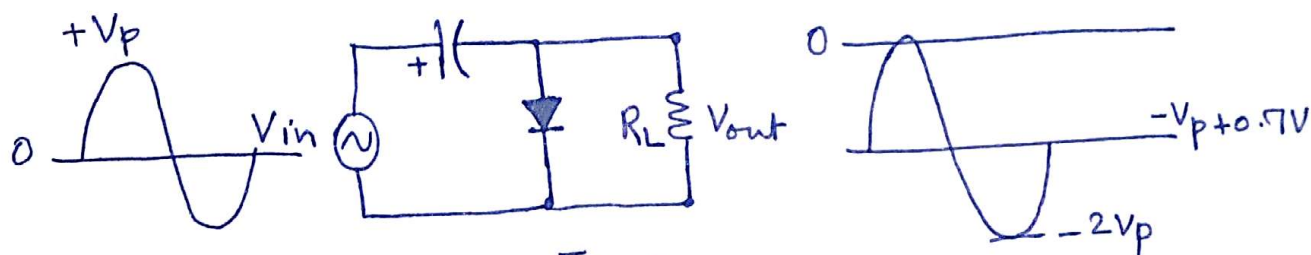


Fig. 3.

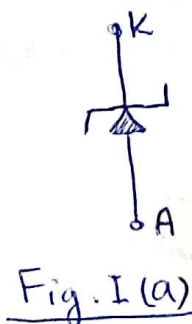
The net effect of the clamping action is that the capacitor retains a charge approximately equal to the peak value of the input less than the diode drop. The capacitor voltage acts as a battery in series with the input voltage. The dc voltage of the capacitor adds to the input voltage by superposition as shown in Fig 2 & 3. If the diode is turned around, a negative dc voltage is added to the input voltage.

The $R_L C$ time constant is deliberately made much larger than the period T of the signal. i.e.

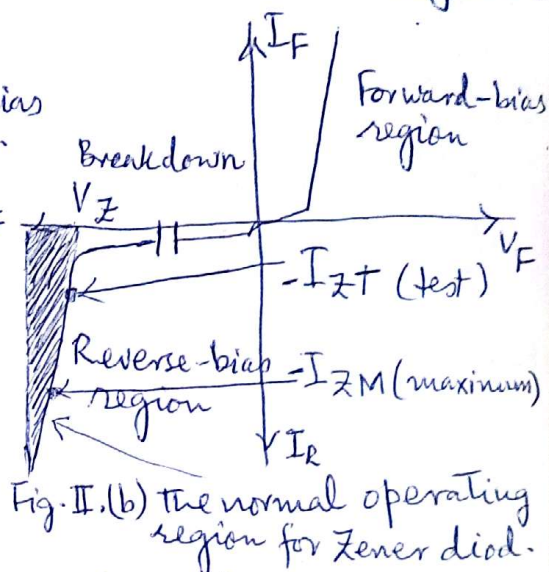
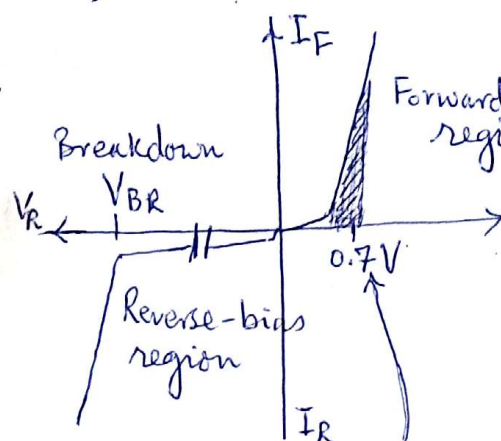
Stiff clamper: $R_L C > 100T$
For this reason, the capacitor remains fully charged during the off time of the diode.

5.1. The Zener Diode.

(6) The symbol for a Zener diode is shown in Fig. 1(a)



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The Zener diode is a silicon pn junction device that differs from rectifier diodes because it is designed for operation in the reverse breakdown region. The breakdown voltage of a Zener diode is set by carefully controlling the doping level during manufacture.

We know that when a rectifier diode reaches reverse breakdown, its voltage remains almost constant even though the current changes drastically. This voltage-current characteristic is shown in Fig. II (a). When a Zener diode is forward-biased, it operates the same as a rectifier diode and for reverse-bias region the normal operating is in the shaded region as shown in Fig. II (b).

Zener diodes are designed to operate in reverse breakdown. Two types of reverse-breakdown in a Zener diode are avalanche and Zener.

The avalanche breakdown occurs in rectifier and Zener diodes at a sufficiently high reverse voltage. Zener breakdown occurs in a Zener diode at low reverse voltages. A Zener diode is heavily doped to reduce the breakdown voltage. This causes a very thin depletion region. As a result, an intense electric field exists within the depletion region. Near the Zener breakdown voltage (V_Z), the field is intense enough to pull electrons from their valence bands and create current.

Zener diodes with breakdown voltages less than 5V operate predominately in Zener breakdown. Those with breakdown voltages greater than approximately 5V operate predominately in avalanche breakdown. Both diodes, however, are called Zener diodes. Zeners are commercially available with breakdown voltages of 1.8V to 200V with specified tolerances from 1% to 20%. The Zener impedance Z_Z is the ratio of ΔV_Z to ΔI_Z as expressed in the following equation

$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z} \quad \text{--- (1)}$$

where I_Z is the reverse current also called the Zener current.

Chapter 6

①

⑦

Basic Electronics
For M.Sc. Physics.

Lecture 10

Ref: Electronic Principle
By: Malvino, PP-189
Sixth Edition.

Bipolar Junction Transistor (BJT)

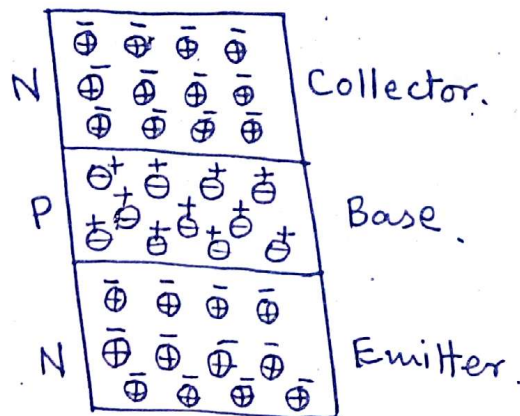
Introduction:- In 1951, William Shockley invented the first junction transistor, a semiconductor device that can amplify electronic signals such as radio and television signals. The transistor has led to many other semiconductor inventions including the integrated circuit (IC), a small device that contains thousands of miniaturized transistors. The word bipolar is an abbreviation for "two polarities."

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§ 6.1. The Unbiased Transistor.

The transistor has three doped regions, as shown in Fig. I.

Structure of a transistor.



The bottom region is called the emitter, the middle region is the base and the top region is the collector. The transistor in Fig. I is an npn transistor, because there is a p region between two n-regions. The majority carriers are free electrons.

in n-type material and holes in p-type material.

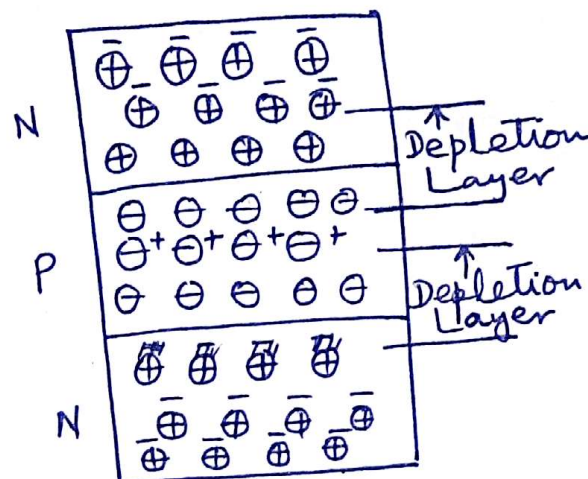
Transistors are also manufactured as pnp devices. A pnp transistor has an n-type region between two p-type regions.

§§ Doping Levels:- The emitter is heavily doped. The base is lightly doped. The doping level of the collector is intermediate, between the heavy doping of emitter and light doping of base. The collector is physically the largest of the three regions.

§§ Emitter and Collector Diodes. The transistor has two junctions, one between the emitter & the base and another between the collector and the base. Because of this, a transistor is like two back to back diodes. The lower diode is called the emitter-base diode. The upper diode is called the collector-base diode, or collector diode.

§§ Before and After Diffusion:- Fig. I shows the transistor regions before diffusion has occurred. As we know, free electrons in the n region will diffuse across the junction and recombine with the holes in the p-region.

The result is two depletion layers as shown in Fig. II.



For each of these depletion layers, The barrier potential is approximately 0.7 volts at $\approx 25^\circ\text{C}$ for a silicon transistor. (0.3V at 25°C for germanium transistor).

§ 6.2. The Biased Transistor:-

An unbiased transistor is like two back-to-back diodes. Each diode has a barrier potential of approximately 0.7V. When an external voltage source is connected to the transistor a current will flow through different parts of the transistor.

§§ Emitter Electrons:-

Fig. III shows the biased transistor, the minus signs free electrons. The heavily doped emitter emit or inject its free electrons into the base. the lightly doped base pass emitter-injected electrons on to the collector. The collector

is so named because it collects or gathers most of the electrons from the base.

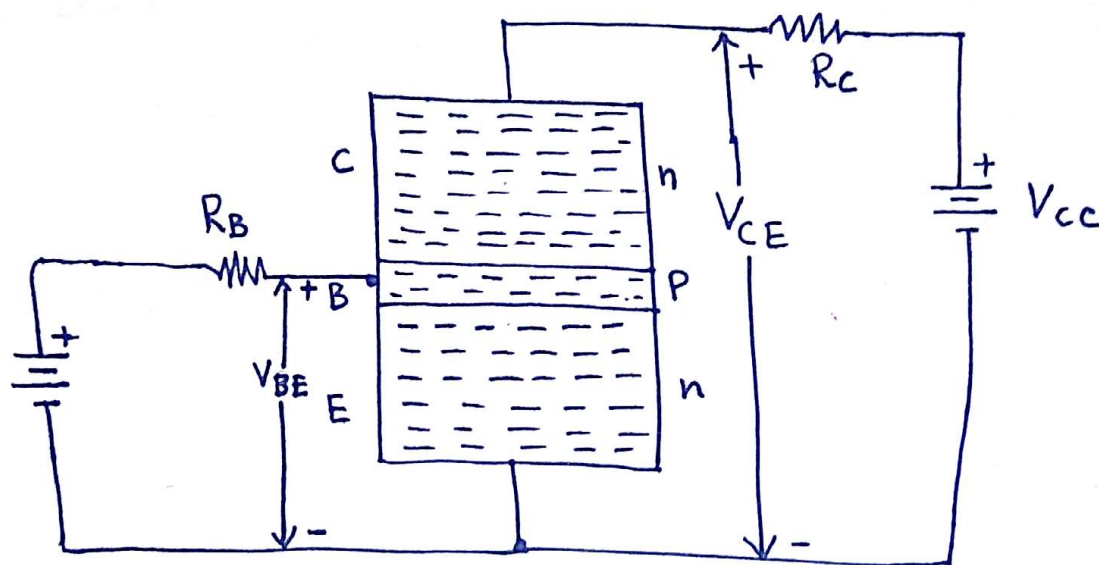
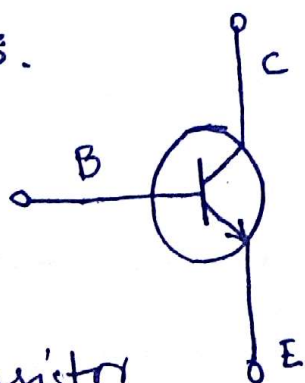


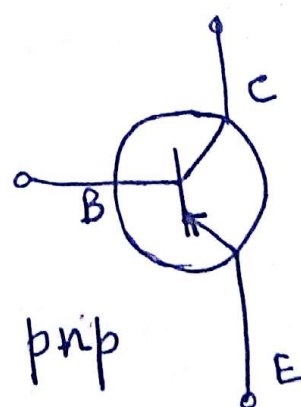
Fig. III Biased Transistor

Fig. III shows the usual way to bias a transistor. The left source V_{BB} of the Fig(III) forward biases the emitter diode and the right source V_{CC} reverse-biases the collector diode. Although other methods are possible, forward-biasing the emitter diode and reverse-biasing the collector diode produce the most useful results.



n/p/n transistor

Symbolic representation



p/n/p

transistor symbol.

Fig. IV

①

§§ Base Electrons :-

When forward bias is applied to the emitter diode and if V_{BB} is greater than the emitter-base barrier potential, emitter electrons will enter the base region. The base is lightly doped and very thin. The light doping means that the free electrons have a long lifetime in the base region. The very thin base means that the free electrons have only a short distance to go to reach the collector. For these two reasons, almost all the emitter-injected electrons pass through the base to the collector.

Only a few electrons will recombine with holes in the lightly doped base region. Then, as valence electrons, they will flow through the base resistor to the positive side of the V_{BB} supply.

Lecture #11
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§§ Collector Electrons :- Almost all the free electrons go into the collector. Once they are in the collector, they feel the attraction of the V_{CC} source voltage. Because of this, the free electrons flow through the collector and through R_C until they reach the positive terminal of the collector supply voltage.

§ 6.3 Transistor Currents

Fig. I Shows the schematic symbol for a transistor.

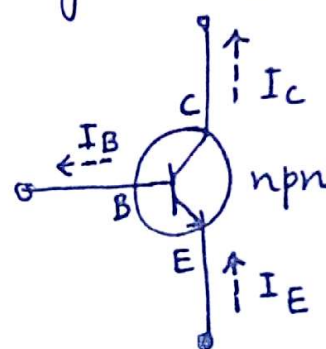
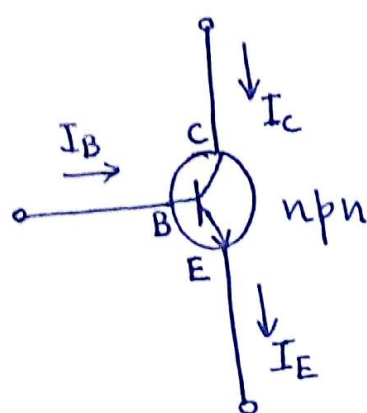


Fig. I.

a) Conventional flow

b) electron flow

There are three different currents in a transistor: emitter current I_E , base current I_B and collector current I_C .

Since emitter is the source of electrons, it has the largest current. Because most of the emitter electrons flow to the collector, the collector current is almost as large as the emitter current. The base current is very small, often less than 1 percent of the collector current.

§§ Relation of currents

According to Kirchhoff's current law, the sum of all currents into a point or junction equals the sum of all currents out of the point or junction. When applied to a transistor, Kirchhoff's current law gives

$$I_E = I_C + I_B \quad \text{--- (I).}$$

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Since the base current is very small, the collector current approximately equals the emitter current:

$$I_C \approx I_E \quad \text{--- (II)}$$

and The base current is much smaller than The collector current:

$$I_B \ll I_C \quad \text{--- (III)}$$

§§ Alpha (α_{dc}): The dc alpha (symbolized α_{dc}) is defined as the ratio of the collector current to the emitter current:

$$\alpha_{dc} = \frac{I_C}{I_E} \quad \text{--- (IV)}$$

Since the collector current almost equals the emitter current, the dc alpha is slightly less than 1. For instance, in a low-power transistor the dc alpha is typically greater than 0.99. Even in high power transistor α_{dc} is typically greater than 0.95.

§§ Beta (β_{dc}): The dc beta (symbolized β_{dc}) of a transistor is defined as the ratio of the dc collector current to the dc base current:

$$\beta_{dc} = \frac{I_C}{I_B} \quad \text{--- (V)}$$

The dc beta is also known as the current gain because a small base current produces a much larger collector current.

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For low power transistors (under 1W), the current gain is typically 100 to 300. High power transistors (over 1W), the current gain is typically 20 to 100.

§§ Relationship of β_{dc} and α_{dc}

Consider The current formula for a biased transistor;

$$I_E = I_C + I_B$$

Dividing each current by I_C :

$$\frac{I_E}{I_C} = \frac{I_C}{I_C} + \frac{I_B}{I_C}$$

Since $\beta_{dc} = I_C/I_B$ & $\alpha_{dc} = I_C/I_E$, we can substitute The reciprocals into The Eqn.

$$\begin{aligned} \text{or } \frac{1}{\alpha_{dc}} &= 1 + \frac{1}{\beta_{dc}} & \left[\beta_{dc} = \frac{I_C}{I_B} \right. \\ & & \left. \& \alpha_{dc} = I_C/I_E \right] \\ \frac{1}{\alpha_{dc}} &= \frac{\beta_{dc} + 1}{\beta_{dc}} \end{aligned}$$

or

$$\beta_{dc} = \alpha_{dc} (\beta_{dc} + 1)$$

$$\beta_{dc} = \alpha_{dc} \beta_{dc} + \alpha_{dc}$$

$$\beta_{dc} - \alpha_{dc} \beta_{dc} = \alpha_{dc}$$

$$\beta_{dc} (1 - \alpha_{dc}) = \alpha_{dc}$$

$$\beta_{dc} = \frac{\alpha_{dc}}{1 - \alpha_{dc}} \quad \text{--- (I)}$$

Eqn (I) shows That The closer α_{dc} is to 1, the higher The value of β_{dc} .

Two Derivations:-

The current gain Eqn. of a transistor is given by

$$\beta_{dc} = \frac{I_c}{I_B} \quad \text{--- (I)}$$

The above Eqn. can be rearranged into two equivalent forms. i.e.

$$I_c = \beta_{dc} I_B \quad \text{--- (II)}$$

When you have the value of β_{dc} & I_c you can calculate the base current with this derivation:

$$I_B = \frac{I_c}{\beta_{dc}} \quad \text{--- (III)}$$

See Exp. 6.1, Example 6.2 & Example 6.3.

Current and Voltage Analysis.

Consider the circuit shown in Fig. I.

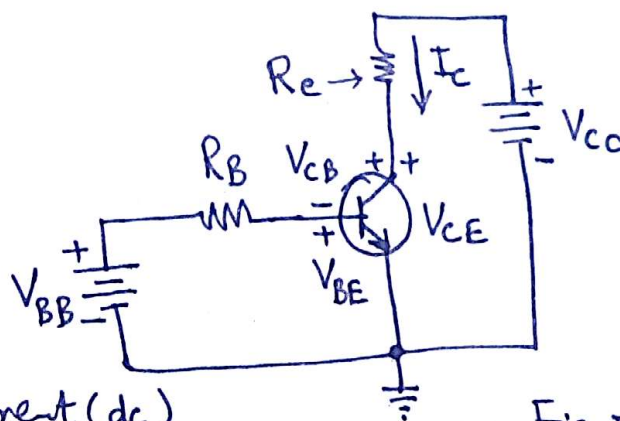


Fig. I Transistor currents & voltages

I_B : Base current (dc)

I_E : Emitter current (dc)

I_c : Collector current (dc)

V_{BE} : DC voltage at base with respect to emitter

V_{CB} : DC voltage at collector with respect to base

V_{CE} : DC voltage at collector with respect to emitter.

V_{BB} forward-biases the emitter-base junction and

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V_{CC} reverse-biases the collector-base junction. When the emitter-base junction is forward-bias, it is like a forward biased diode and has a forward voltage drop of

$$V_{BE} \approx 0.7V \quad \text{--- (i)}$$

Since the emitter is at ground (0V), by Kirchhoff's voltage law, the voltage across R_B is

$$V_{RB} = V_{BB} - V_{BE} \quad \text{--- (ii)}$$

also by Ohm's law $V_{RB} = I_B R_B$ --- (iii)

putting the value of V_{RB} from Eqn (ii) in Eqn (iii) we get

$$I_B R_B = V_{BB} - V_{BE}$$

Solving for I_B , we get

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \quad \text{--- (iv)}$$

the drop across R_E is

$$V_{RE} = I_E R_E \quad \text{--- (v)}$$

the voltage at the collector with respect to the emitter, which is grounded, is

$$V_{CE} = V_{CC} - I_C R_E \quad \text{--- (vi)}$$

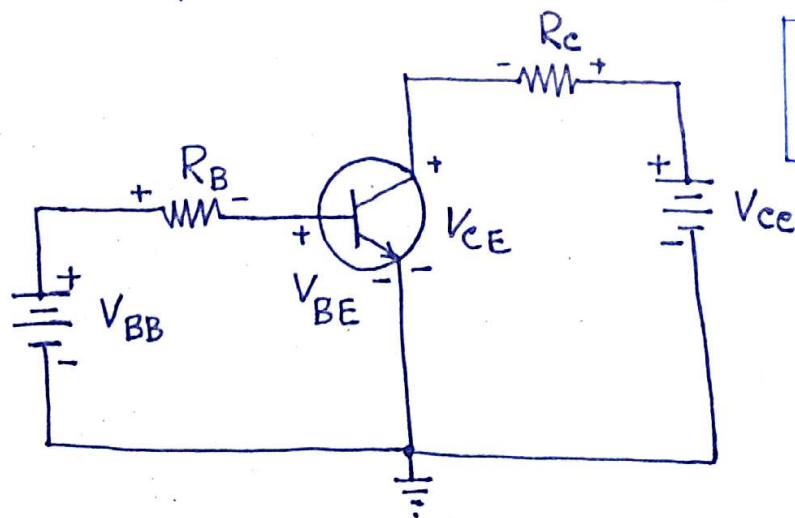
where $I_C = \beta_{DC} I_B$. the voltage across the reverse-biased collector-base junction is

$$V_{CB} = V_{CE} - V_{BE} \quad \text{--- (vii)}$$

4. The Common Emitter Connection (CE).

There are three ways to connect a transistor: with a CE (common emitter) or a common base (CB) or a CC (Common collector). We will focus on the CE connection because it is the most widely used.

§§. Common Emitter (CE). A common emitter (CE) configuration is shown in Fig. I. in which the common or ground side of each voltage source is connected to the emitter. The circuit has two loops. The left loop is the base loop and the right loop is the collector loop.



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Fig. 1. CE Connection.

In the base loop, the V_{BB} source forward-biases the emitter diode with R_B as a current-limiting resistance. By changing V_{BB} or R_B , we can change the base current. Changing the base current will change the collector current. In other words, the base current controls the collector current.

It means that a small base current controls a large collector current. In the collector loop, a source voltage V_{CC} reverse-biases the collector diode through R_C . The collector must be positive to collect most of the free electrons injected into the base.

In Fig. I, the flow of base current in the left loop produces a voltage across the base resistor R_B with the polarity shown. Similarly, the flow of collector current in the right loop produces a voltage across the collector resistor R_C with the polarity shown.

§§ Double Subscripts :- Double-subscript notation is used with transistor circuits. When the subscripts are the same, the voltage represents a source (V_{BB} & V_{CC}). When the subscripts are different, the voltage is between the two points, (V_{BE} and V_{CE}).

§§ Single Subscripts :- Single subscripts are used for node voltages, that is, voltages between the ground and the subscript point. For example V_B is the voltage between the base and ground, Voltage V_C is the voltage between the collector and ground.

§ 5.5 The Base Curve.

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The graph of I_B versus V_{BE} looks like the graph of an ordinary diode as shown in Fig. 2.

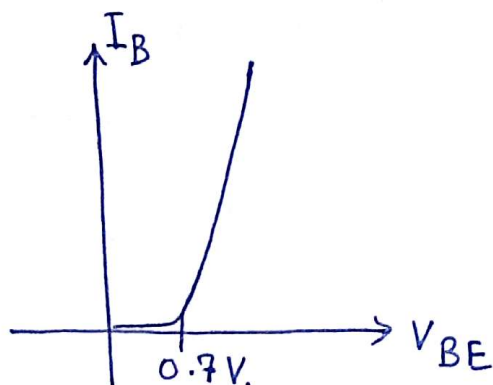


Fig. 2. I_B versus V_{BE} .

This is a forward biased emitter diode. Applying Ohm's law to the base resistor in Fig. 1 gives this derivation:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \quad \text{--- (I)}$$

For an ideal diode, $V_{BE} = 0$. With the second approximation, $V_{BE} = 0.7V$. The second approximation is the best compromise.

§ 6.6 The Collector Curve.

We can vary V_{BB} and V_{CC} in Fig. 1 to produce different transistor voltages and currents. By measuring I_C and V_{CE} , we can get data for a graph of I_C versus V_{CE} .

For instance, suppose we change V_{BB} as needed to get $I_B = 10\mu A$. With this fixed value of base current, we can now vary V_{CC} and measure I_C and V_{CE} . Plotting the data gives the graph as

in Fig. 3.

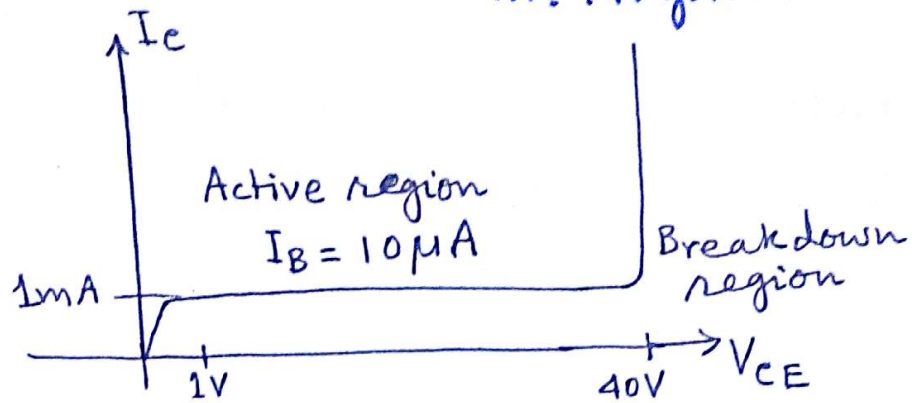


Fig. 3. The collector curve.

This graph is for a 2N3904, a widely used low-power transistor. With other transistors, the numbers may vary but the shape of the curve will be similar.

When V_{CE} is zero, the collector diode is not reverse biased. This is why the graph shows a collector current of zero when V_{CE} is zero. When V_{CE} increases from zero, the collector current rises sharply. When V_{CE} is a few tenths of a volt, the collector current becomes almost constant and equal to 1 mA. After the collector diode becomes reverse-biased, it is gathering all the electrons that reach its depletion layer. Further increases in the V_{CE} cannot increase the collector current. Why? Because the collector can collect only those free electrons that the emitter injects into the base. The number of these injected electrons depends only on the base circuit, not on the collector circuit. This is why Fig. 3 a constant

Collector curve is shown.

If V_{CE} is greater than 40V, the collector diode breaks down and the normal transistor action is lost. For this reason, one of the maximum ratings to look for a transistor data sheet is the collector-emitter breakdown voltage $V_{CE(max)}$.

§§ Collector Voltage and Power.

Kirchhoff's voltage law says that the sum of voltage around a loop or closed path is equal to zero. When applied to the collector circuit of Fig 1.

Kirchhoff's voltage law gives us this derivation:

$$V_{CE} = V_{CC} - I_C R_C \quad \text{--- (II)}$$

In Fig 1 the transistor has a power dissipation of approximately:

$$P_D = V_{CE} I_C \quad \text{--- (III)}$$

This power dissipation causes the junction temperature of the collector diode to increase. The higher the power, the higher the junction temperature. Transistor will burn out when the junction temperature is between 150 and 200°C.

One of the most important pieces of information on a data sheet is the maximum power rating $P_{D(max)}$. The power dissipation given by Eqn. (III)

must be less than $P_{D(max)}$. Otherwise the transistor will be destroyed.

§§. Hybrid Parameters:- Hybrid (h) parameters are

① important because they are typically specified on a manufacturer's data sheet. These parameters are specified by manufacturers because they are relatively easy to measure.

The four h-parameters are h_i , h_r , h_f and h_o . The four basic h-parameters and their descriptions are given in table 6-1. Each of the four h-parameters carries a second subscript letter to designate the common-emitter (e), common-base (b), or common-collector (c) configuration.

h-parameter	Description	Condition
h_{ie}	Input impedance (resistance)	Output shorted
h_{re}	Voltage feedback ratio	input open
h_{fe}	Forward current gain	output shorted
h_{oe}	Output admittance (conductance)	input open

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Table 6-1 Basic ac h-parameters
Common Emitter Configuration

To define these parameter, a two port network is considered and the h-parameters are represented in general form as h_{11} , h_{12} , h_{21} and h_{22} .

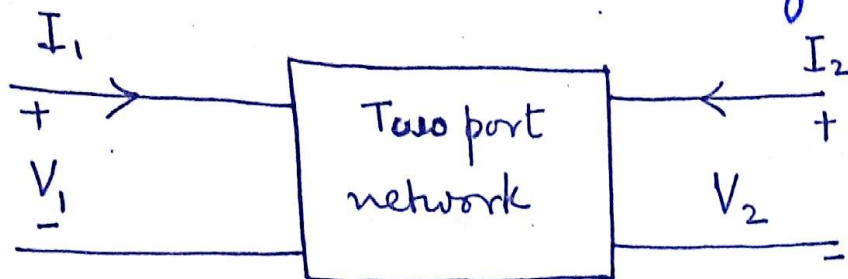


Fig. 1

The quantities that it takes is the dependent variables

$$V_1 = h_{11} I_1 + h_{12} V_2 \quad \text{--- (I)}$$

$\swarrow$ independent variables
 $\nwarrow$ dependent variables

$$I_2 = h_{21} I_1 + h_{22} V_2 \quad \text{--- (II)}$$

or in matrix form:

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix} = h \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

The values of the parameters can be evaluated by setting $I_1 = 0$ (input port open circuited) or $V_2 = 0$ (output port short circuited). Thus, from

Eqn. (I), $h_{11} = \frac{V_1}{I_1} \bigg|_{V_2=0}$ hie (output short circuited).



Fig. 2

$\frac{V_1}{I_1}$ is the input impedance under short circuited output. Since the y_{11} is the admittance therefore

$$h_{11} = \frac{1}{y_{11}}$$

In case of common emitter configuration

The input impedance h-parameters is $h_{ie} = \frac{V_1}{I_1} \bigg|_{V_2=0}$

Also from Eqn. (I)

$$h_{12} = \frac{V_1}{V_2} \bigg|_{I_1=0} \text{ Voltage feedback ratio, } h_{re}$$

Hence h_{12} is the open circuit reverse voltage transfer function. (Voltage feedback ratio, h_{re})

Now from Eqn. (II)

$$h_{21} = \frac{I_2}{I_1} \bigg|_{V_2=0} \text{ current gain } h_{fe}$$

h_{21} is a current transfer function and is a dimensionless quantity. It is also called short circuited current transfer function.

Also, from Eqn. (II)

$$h_{22} = \frac{I_2}{V_2} \bigg|_{I_1=0} \text{ } h_{oe} \text{ output admittance} = \frac{1}{Z_{22}}$$

the unit of admittance or conductance $\frac{1}{\Omega}$ is Siemens.

§ Definition of h-parameters for a common-emitter configuration

Configuration:- Each of the h-parameter is derived from ac measurements taken from operating transistor characteristic curves.

h_{ie} is the ac resistance looking in at the input terminal of the transistor without output shorted, as shown in Fig. 3.

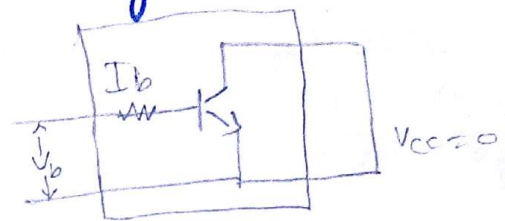
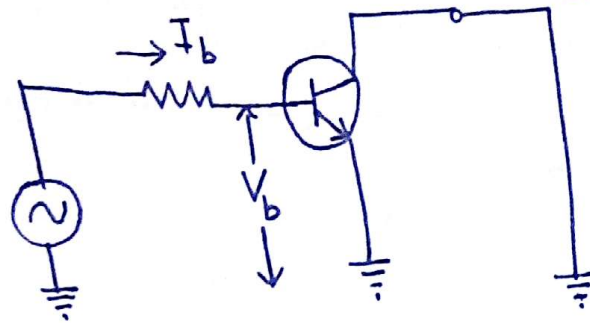


Fig. 3 $h_{ie} = \frac{V_b}{I_b} \Big|_{V_{ce}=0}$

As indicated in Fig. 3, h_{ie} is the ratio of the input voltage (V_b) to the input current (I_b)

h_{re} is a measure of the amount of output voltage that is reflected (fed back) to the input with the input open, i.e., $h_{re} = \frac{V_b}{V_c}$ as shown in Fig. 4

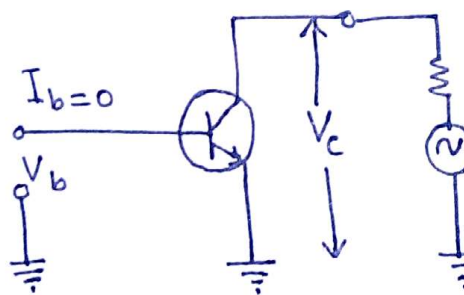


Fig. 4 $h_{re} = \frac{V_b}{V_c} \Big|_{I_b=0}$

h_{fe} is The forward current gain measured with The output (collector) shorted, as shown in Fig. 5

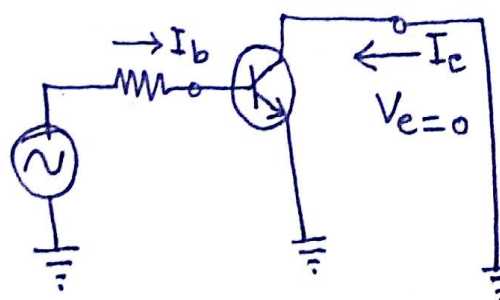


Fig. 5 $h_{fe} = \frac{I_c}{I_b} \Big|_{V_c=0}$

Finally, h_{oe} is The conductance looking in at The output with The input open, as shown in Fig. 6

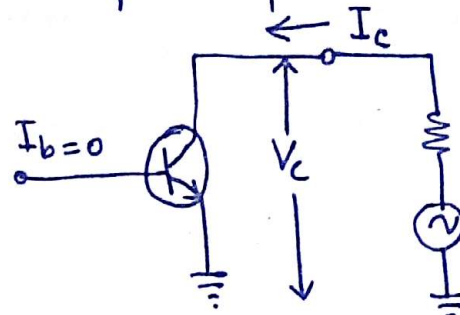
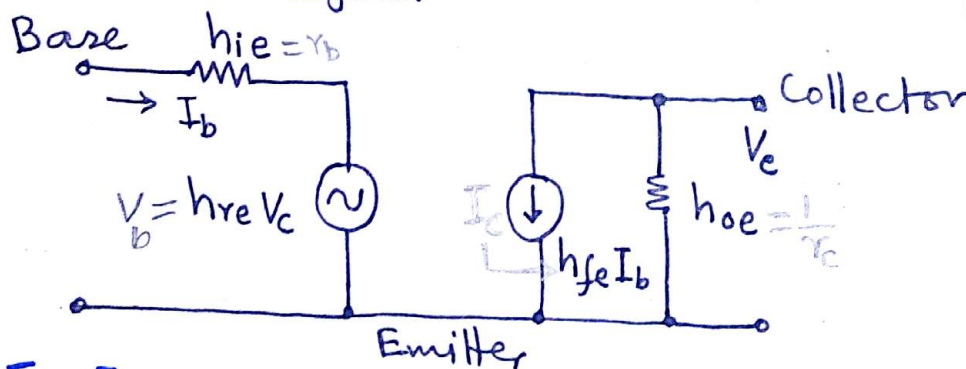


Fig. 6 $h_{oe} = \frac{I_c}{V_c} \Big|_{I_b=0}$

§ Hybrid Equivalent circuit :- Hybrid pi-Equivalent circuit is The most universal and desirable kind of an equivalent circuit. The general form of the h-parameter equivalent circuit is shown in Fig. 7.



$$\begin{aligned} h_{re} &= \frac{V_b}{V_c} \\ h_{re} V_c &= V_b \\ h_{fe} &= \frac{I_c}{I_b} \\ h_{fe} I_b &= \frac{I_c}{I_b} \cdot I_b \\ &= I_c \end{aligned}$$

Fig. 7. Hybrid pi-equivalent circuit for CE configuration

the reverse voltage ratio, h_{re} is multiplied by The output voltage V_c to produce an equivalent voltage source in series with The input. The forward current gain h_{fe} is multiplied by the input current I_b and appears as an equivalent current source in the output. The output conductance h_{oe} appears across the output terminals.

There are two basic ways to set up the operating point of a transistor: base bias and emitter bias.

Base bias produces a fixed value of base current, whereas emitter bias produces a fixed value of emitter current. Base bias is most useful in switching circuits, whereas emitter bias is predominant in amplifying circuits.

Lecture #15
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§ 7.1. Variations in Current Gain.

The current gain β_{dc} of a transistor depends on three factors: The transistor, the collector current and the temperature. For instance when a transistor is replaced with another of the same type, the current gain usually changes. Likewise, if the collector current or temperature changes, the current gain will change. When the temperature decreases, the current gain decreases and when the temperature increases, $h_{FE} = \frac{I_C}{I_B}$ increases over most of the current range.

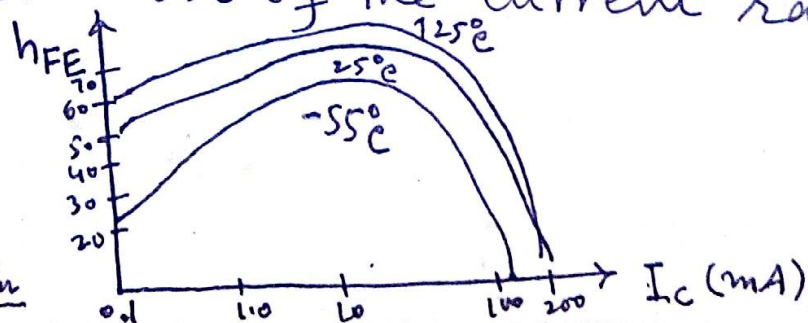


Fig. 7.1. Variation of current gain

§ 7.2. The Load Line.

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Lecture 15

Base Bias:- A common-emitter configuration of an npn transistor is shown in Fig. 7.2

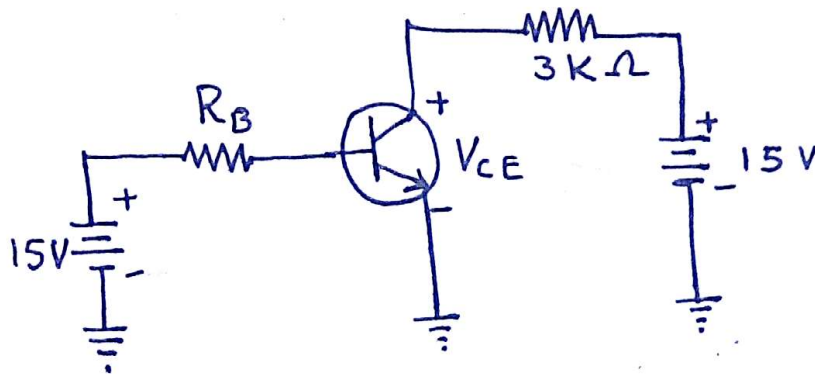


Fig. 7.2. Base-bias circuit.

The circuit of Fig. 7.2 is an example of base bias, which means setting up a fixed value of base current. For example, if R_B is $1\text{ M}\Omega$, the base current is $14.3\text{ }\mu\text{A}$. (Second approximation). Even with transistor replacements or temperature changes, the base current remains fixed under all operating conditions.

If β_{dc} is 100 in Fig. 7.2. The collector current is approximately 1.43 mA and the collector emitter voltage is:

$$V_{CE} = V_{CC} - I_C R_C = 15\text{ V} - (1.43\text{ mA})(3\text{ K}\Omega)$$

$$\text{or } V_{CE} = 10.7\text{ V.}$$

therefore the quiescent or Q point is

$$I_C = 1.43\text{ mA} \text{ and } V_{CE} = 10.7\text{ V}$$

88 Graphical Solution.

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We can also find the Q point using a graphical solution based on the transistor load line, a graph of I_c versus V_{CE} . In Fig 7-2, the collector-emitter voltage is given by:

$$V_{CE} = V_{CC} - I_c R_c \quad \text{--- (I)}$$

Solving for I_c gives:

$$I_c = \frac{V_{CC} - V_{CE}}{R_c} \quad \text{--- (II)}$$

If we graph this equation (I_c versus V_{CE}), we will get a straight line. This line is called the load line because it represents the effect of the load on I_c and V_{CE} .

For instance, substituting the values of Fig. 7.2 into equation (II) gives:

$$I_c = \frac{15V. - V_{CE}}{3K\Omega}$$

This is a linear equation: that is, its graph is a straight line. The ends of the load line are the easiest to find. When $V_{CE} = 0$ in the load line equation:

$$I_c = \frac{15V}{3K\Omega}$$

The values, $I_c = 5\text{ mA}$ and $V_{CE} = 0$, plots as the upper end of the load line as shown in Fig 7.3.

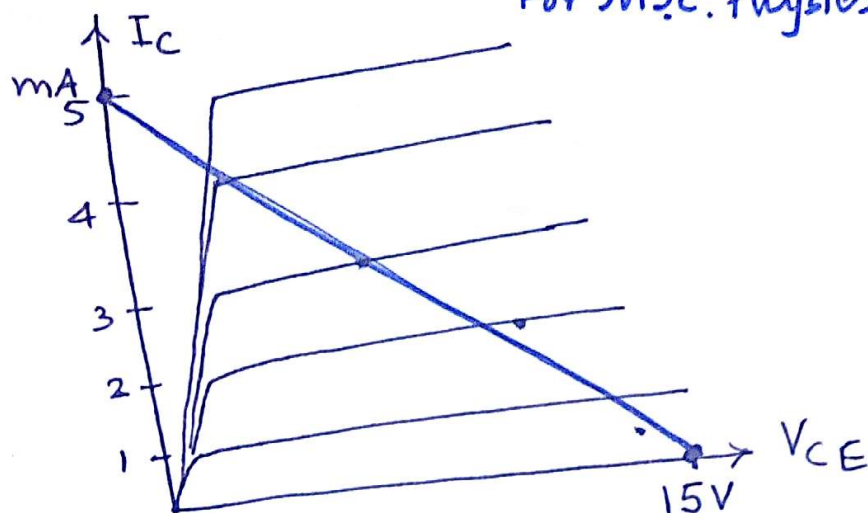


Fig. 7.3. Base bias load line.

When $I_C = 0 \text{ mA}$, the load line equation gives:

$$0 = \frac{15\text{V} - V_{CE}}{3\text{K}\Omega}$$

or

$$V_{CE} = 15\text{V}$$

The coordinates, $I_C = 0$ and $V_{CE} = 15\text{V}$ plot as the lower end of the load line as shown in Fig. 7.3.

Load line is useful because it contains every possible operating point for the circuit.

§§ The Saturation Point:- When the base resistance

is too small, there is a large collector current, and the collector-emitter voltage drops to approximately zero. In this case, the transistor goes into saturation. This means that the collector current has increased to its maximum possible value.

The saturation point is the point in Fig. 7.3 where the load line intersects the saturation region.

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of the collector curves. Because the collector-emitter voltage V_{CE} at saturation is very small, the saturation point is almost touching the upper end of the load line.

The saturation point tells us the maximum possible collector current for the circuit. For example, the transistor in Fig. 7.2 goes into saturation when the collector current is approximately 5mA. At this current, V_{CE} has decreased to approximately zero. i.e.

$$I_c = \frac{15V}{3k\Omega} = 5mA.$$

To find the current at the saturation point visualize a short between the collector and emitter.

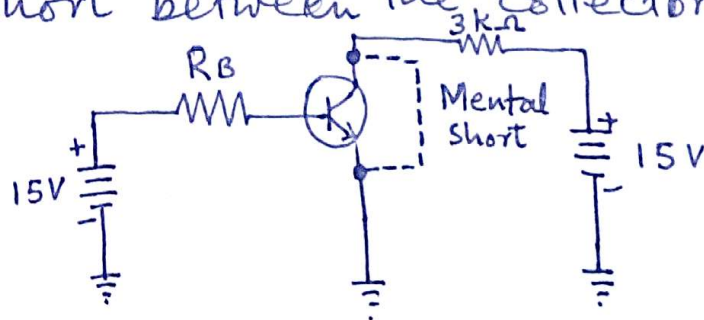


Fig. 7.4. Collector saturation current

We can apply this "mental short" method to any base-biased circuit.

The formula for the saturation current in base-biased circuit is given by

$$I_{c(sat)} = \frac{V_{CC}}{R_C}$$

That is, the max. collector current equals the collector supply voltage divided by the collector resistance.

§§ The cutoff Point.

The cutoff point is the point at which the load line intersects the cutoff region of the collector curve in Fig 7.3. Because the collector current at cutoff is very small, the cutoff point almost touches the lower end of the load line. We can approximate the cutoff point as the lower end of the load line.

The cutoff point tells us the maximum possible V_{CE} for the circuit. In Fig. 7.2 the maximum possible V_{CE} is approximately 15V, the collector supply voltage.

There is a simple process for finding the cutoff voltage. Visualize the transistor as an open between the collector and the emitter as shown in Fig. 7.5

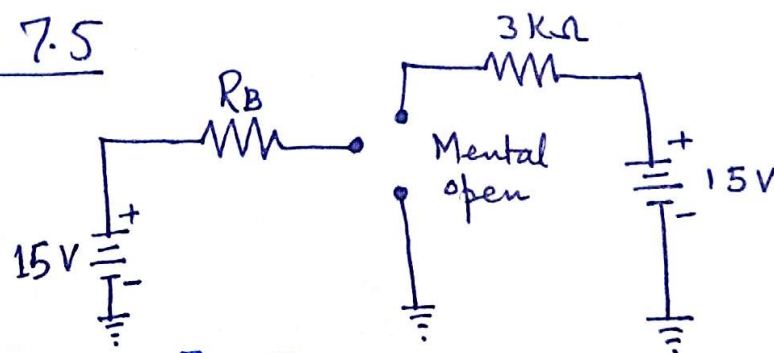


Fig. 7.5.

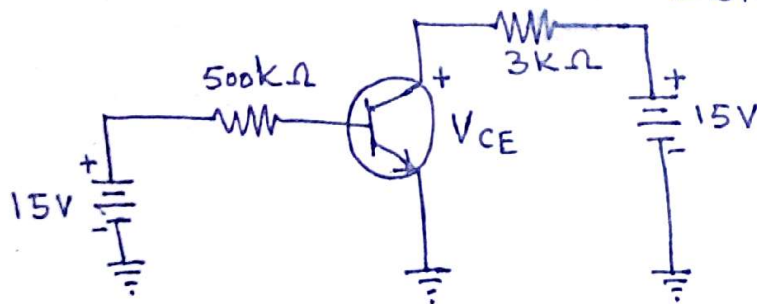
Since there is no current through the collector resistance for this open condition, all the collector supply will appear between the collector emitter terminal, i.e.,

$$V_{CE(\text{cutoff})} = V_{CC}$$

7.3 The Operating Point (1 point) Basic Electronics Lecture 16 For MSc. Physics (2)

Every transistor circuit has a load line. Given any circuit, work out the saturation current and the cutoff voltage. These values are plotted on the vertical and horizontal axes. Then draw a line through these two points to get the load line.

Plotting the Q Point. Fig. 1 shows a base-biased circuit with a base resistance of $500\text{k}\Omega$.



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Fig. 1 Base-biased (CE) circuit

We can find the saturation current $I_C = 5\text{mA}$ and cutoff voltage $V_{CE} = V_{CC} = 15\text{V}$. If we plot the saturation current and cutoff voltage, we can draw the load line as shown in Fig. 2.

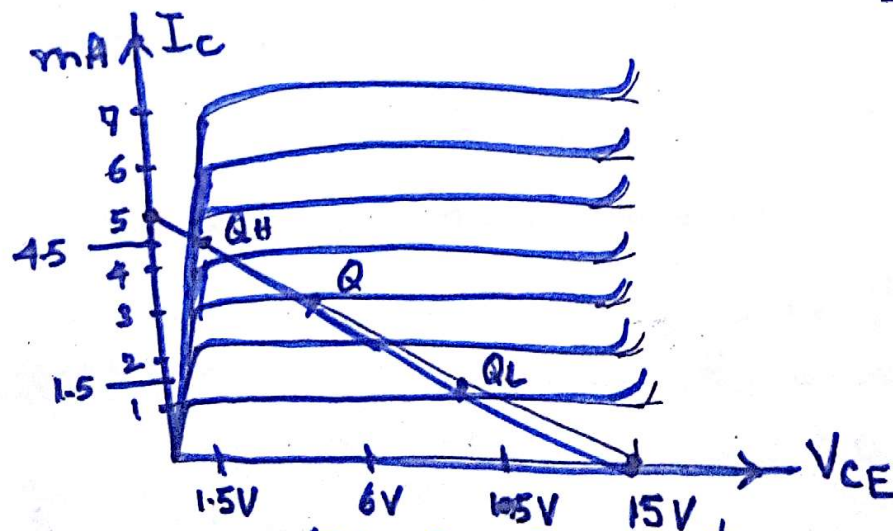


Fig. 2. Q. point.

②

For an ideal transistor

$$I_B = \frac{15V}{500k\Omega} = 30\mu A$$

Now for the above value of I_B , The collector current I_C is given by ($\beta_{dc} = 100$)

$$I_C = 100(30\mu A) = 3mA$$

This current flows through $3k\Omega$ produces a voltage of $9V$ across the collector resistor.

Hence $V_{CE} = 15V - (3mA)(3k\Omega) = 6V$.

By plotting $3mA$ and $6V$ (the collector current and voltage we get the operating point shown on the load line of Fig. 2.

The operating point is labeled Q , because

This point is often called the quiescent

point. (Quiescent means quiet still or resting). Note that the three Q -points in the

Fig. 2 are for $\beta_{dc} = 50$; $\beta_{dc} = 100$ & $\beta_{dc} = 150$.

plotting the values I_C & V_{CE} for different β_{dc} gives the low Q_L point & high point Q_H as shown

in Fig. 2. the three Q -points of Fig. 2 illustrate

how sensitive the operating point of the base-biased transistor is to change in β_{dc} .

The formulae for calculating the Q -point as follows:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}, \quad I_C = \beta_{dc} I_B$$

$$V_{CE} = V_{CC} - I_C R_C$$

§ 7.5. the transistor Switch.

Base bias is useful in digital circuits because these circuits are usually designed to operate at saturation and cutoff. Because of this they have either low output or high output voltage. In other words, none of the Q-points between saturation and cutoff are used. For this reason, variations in Q-point don't matter.

The transistor in Fig-3 is used as a switch to turn the LED on and off.

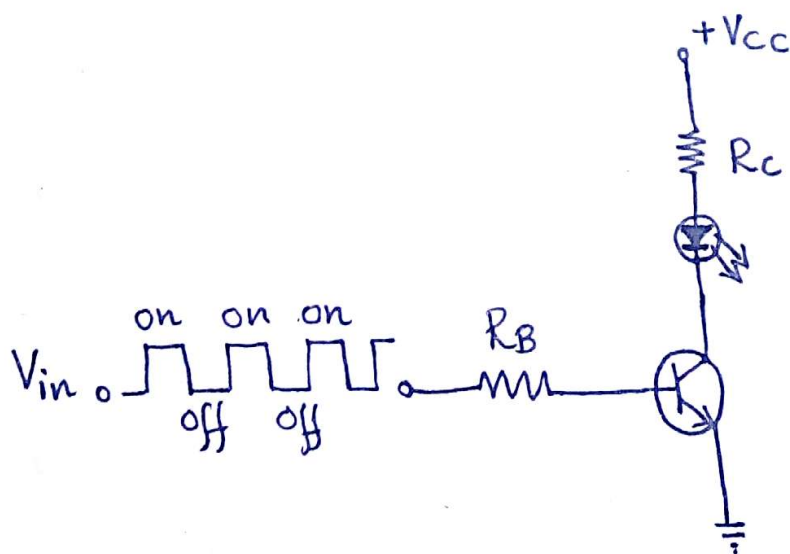


Fig.3. the transistor switch

For example a square wave input voltage with a period of 2 seconds is applied to the input. When the square wave is at 0V, the transistor is in cutoff and, since there is no collector current, the LED does not emit light. When the square wave goes to its high level, the transistor saturates. This forward biases the LED and causes it to emit light.

§ 7.6 Emitter Bias.

Digital circuits are used in computers. In this area base-bias circuits are useful. But when it comes to amplifiers, we need circuits whose Q points are immune to changes in current gain. Fig. 4 shows emitter bias circuit

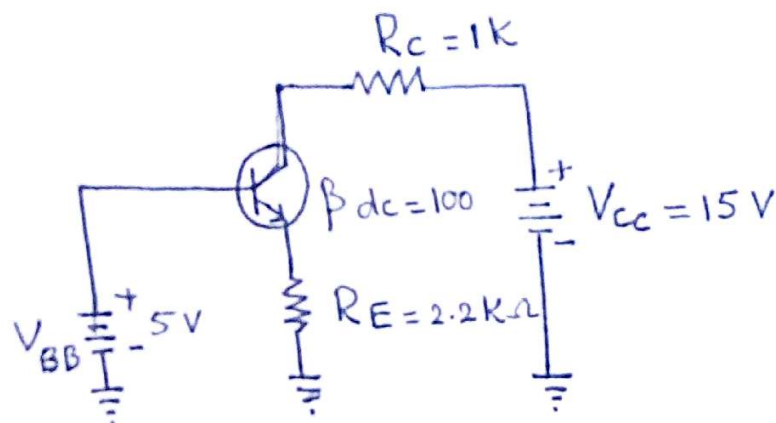


Fig. 4 Emitter bias

As can be seen, the resistor has been moved from the base to the emitter. The Q point of this new circuit is now rock-solid. When the current gain changes from 50 to 150, the Q point shows almost no movement along the load line. The base supply voltage is now applied directly to the base. The emitter is no longer grounded. The voltage at the emitter is given by

$$V_E = V_{BB} - V_{BE}$$

V_E can be found using second approximation for which $V_{BE} = 0.7V$.

55 Finding The Q-point.

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To analyze the emitter-biased circuit shown in Fig-4 consider the base supply voltage is only 5V. Using second approximation, the emitter voltage is given by

$$V_E = 5 - 0.7V = 4.3V$$

This voltage is across the emitter resistance, so we can use Ohm's law to find the emitter current

$$I_E = \frac{4.3V}{2.2K\Omega} = 1.95mA \approx I_C$$

When this collector current flows through the collector resistor, it produces a voltage drop of 1.95 V. Subtracting this from the collector supply voltage gives the voltage between the collector and the ground:

$$V_C = 15V - (1.95mA)(1K\Omega)$$

$$V_C = 13.1V$$

Hence,

$$V_{CE} = V_C - V_E = 13.1 - 4.3$$

$$\text{or } V_{CE} = 8.8V$$

So the emitter bias circuit has a Q-point with these coordinates: $I_C = 1.95mA$ & $V_{CE} = 8.8V$. The collector emitter voltage is used drawing load lines and for reading transistor data sheets. As a formula

$$V_{CE} = V_C - V_E.$$

§ 9.1. Base-Biased Amplifier.

③ Although base-biased amplifier is not useful in mass production, it has instructional value because its basic idea can be used to build more complicated amplifiers.

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§§. Coupling Capacitor. Fig. 9.1 shows an ac voltage source connected to a capacitor and a resistor. Since the impedance of the capacitor is inversely proportional to frequency, the capacitor effectively blocks dc voltage and transmits ac voltage. When the frequency is high enough, the capacitive reactance is much smaller than the resistance. In this case almost all the ac source voltage appears across the resistor. When used in this way the capacitor is called a coupling capacitor because it couples or transmits the ac signal to the resistor.

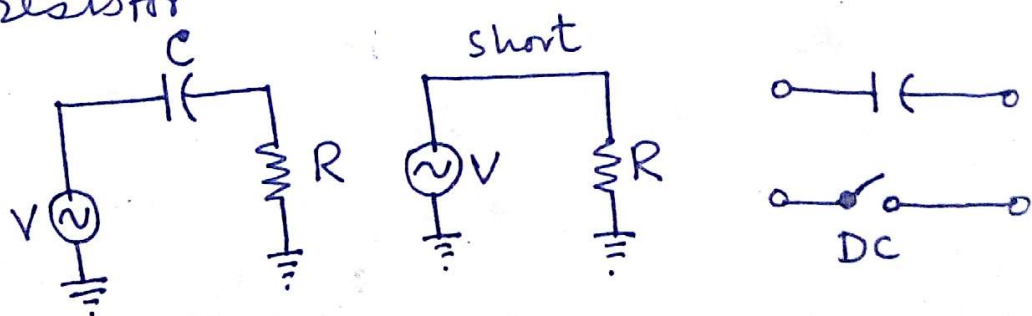


Fig. 9.1. Coupling capacitor

AC

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For a coupling capacitor to work properly, its reactance must be much smaller than the resistance at the lowest frequency of the ac source. The reactance should be at least 10 times smaller than the resistance at the lowest frequency of operation. i.e., for good coupling

$$X_c < 0.1 R.$$

When the 10:1 rule is satisfied, Fig. 9.1(a) can be replaced by the equivalent circuit of Fig. 9.1(b). The magnitude of the impedance in Fig. 9.1(a) is given by

$$Z = \sqrt{R^2 + X_c^2}$$

From the relation $X_c = \frac{1}{2\pi f_c}$, since dc voltage has frequency of zero, the reactance of the coupling capacitor is infinite. Therefore, for dc analysis, the capacitor is open whereas for ac analysis the capacitor is shorted.

§§ DC Circuit. Fig. 9.2(a) shows a base-biased circuit. the dc base voltage is 0.7 V, the base current is then given by

$$I_B = \frac{V_B}{R_B} = \frac{30 \text{ V}}{10^6 \Omega} = 30 \mu\text{A}$$

or

$$I_B = 30 \mu\text{A}.$$

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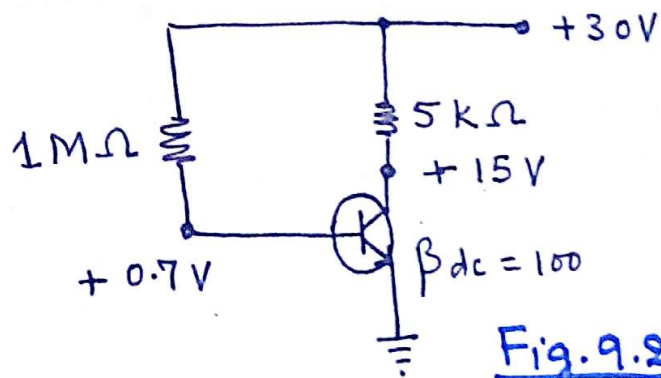


Fig. 9.2(a) base-bias

With The current gain of 100, The collector current is:

$$I_c = 3 \text{ mA}$$

And The collector voltage is

$$V_c = 30 - (3 \text{ mA})(5 \text{ k}\Omega)$$

$$V_c = 15 \text{ V}$$

So, The Q-point is located at 3mA and 15V.

§§. Amplifying Circuit. Fig. 9.2 b shows how to add components to build an amplifier.

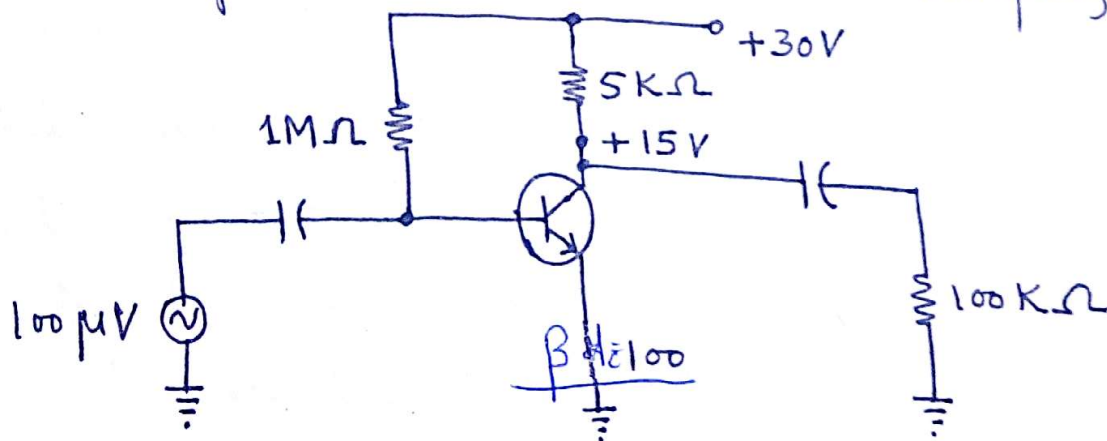


Fig. 9.2. b. Base-biased amplifier.

A coupling capacitor is used between an ac source and the base. Since the coupling capacitor is open to direct current, The same dc current exists with or without the capacitor. Similarly,

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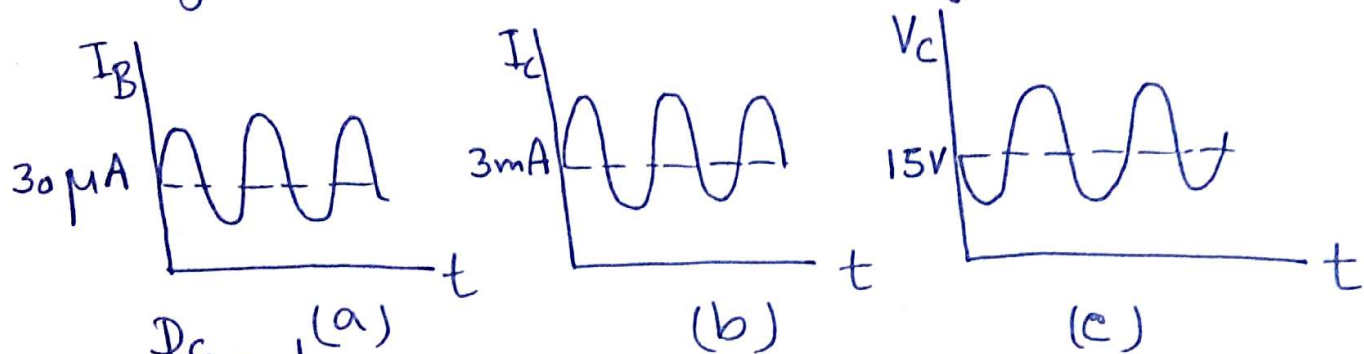
a coupling capacitor is used between the collector and the load resistor of $100\text{ k}\Omega$. Since this capacitor is open to direct current, the dc collector voltage is the same with or without the capacitor and load resistor. The key idea is that the coupling capacitor prevents the ac source and load resistance from changing the Q-point.

In Fig. 9.2.b the ac source voltage is $100\text{ }\mu\text{V}$. Since the coupling capacitor is an ac short, all the ac source voltage appears between the base and the ground. This ac voltage produces an ac base current that is added to the existing dc base current. In other words, the total base current will have a dc component and an ac component.

An ac component is superimposed on the dc component. On the positive half cycle, the ac base current adds to the $30\text{ }\mu\text{A}$ dc base current and on the negative half cycle it subtracts from it.

The ac base current produces an amplified variation in collector current because of the current gain. The collector current has a dc component of 3 mA . Superimposed on this is an ac collector current.

Since this amplified collector current flows through the collector resistor, it produces a varying voltage across the collector resistor. The collector voltage curve is shown in Fig.



Dc and ac components.

Fig. 9.3 a) b, c.

a) base current
b) collector current
c) collector voltage.

As can be seen in Fig. 9.3(c), the collector voltage is swinging sinusoidally above and below the dc level of $+15 V$. Also, the ac collector voltage is inverted, 180° out of phase with the input voltage. The reason for this phase shift is that on the positive half cycle of ac base current, the collector current increases, producing more voltage across the collector resistor. This means that there is less voltage between the collector and ground. Similarly, on the negative half cycle, the collector current decreases. Since there is less voltage across the collector resistor, the collector voltage increases.

§ Voltage Wave form.

Fig. 9-4 shows the waveform for a base-biased amplifier. The ac source voltage is a small sinusoidal voltage.

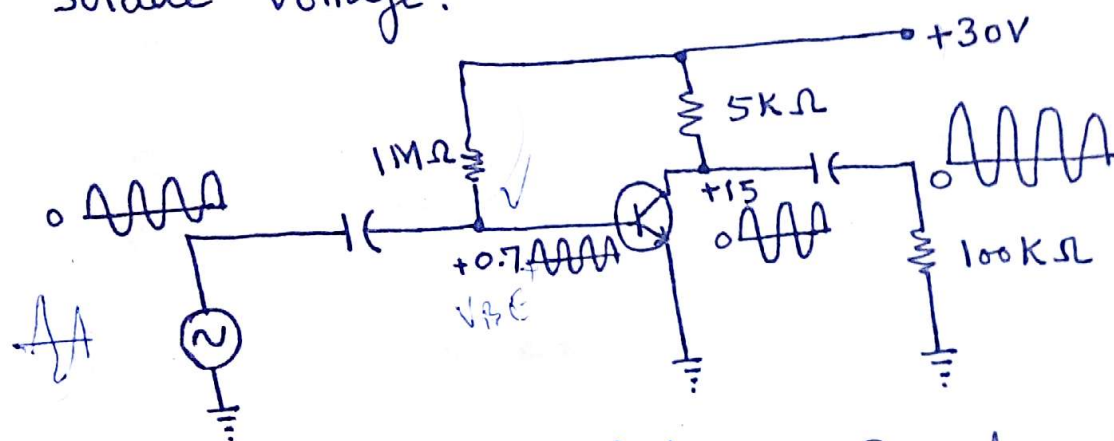


Fig. 9.4. Base Biased amplifier with waveform

This is coupled into the base, where it is superimposed on the dc component of $+0.7V$. The variation in base-voltage produces sinusoidal variations in base current, collector current and collector voltage. The total collector voltage is an inverted sin wave superimposed on the dc collector voltage of $+15V$. The capacitor couples the ac component of the collector voltage to the load resistor R_L . Since the capacitor also blocks the dc component of the collector voltage, hence the load voltage is a pure ac signal. The load voltage amplified form of the input ac voltage but is 180° out of phase with the input voltage.

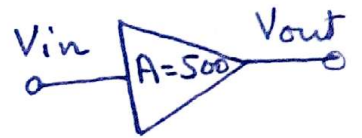
Voltage Gain

The voltage gain "A" of an amplifier is defined as the ac output voltage divided by the ac input voltage, i.e.,

$$A = \frac{V_{out}}{V_{in}} \quad \text{--- (I)}$$

For example, if we measure an ac load voltage of 50mV with an ac input voltage of 100μV. the voltage gain is:

$$A = \frac{50\text{mV}}{100\mu\text{V}} = 500$$



This says that the output voltage is 500 times larger than the ac input voltage.

From Eqn. (I) we can also have

$$V_{out} = A V_{in} \quad \text{--- (II)}$$

Hence if A & V_{in} are known we can find V_{out} .

From Eqn. (I) we can have,

$$V_{in} = \frac{V_{out}}{A} \quad \text{--- (III)}$$

That is, if V_{out} and A of an amplifier are known, we can also find V_{in} using

Eqn. III.

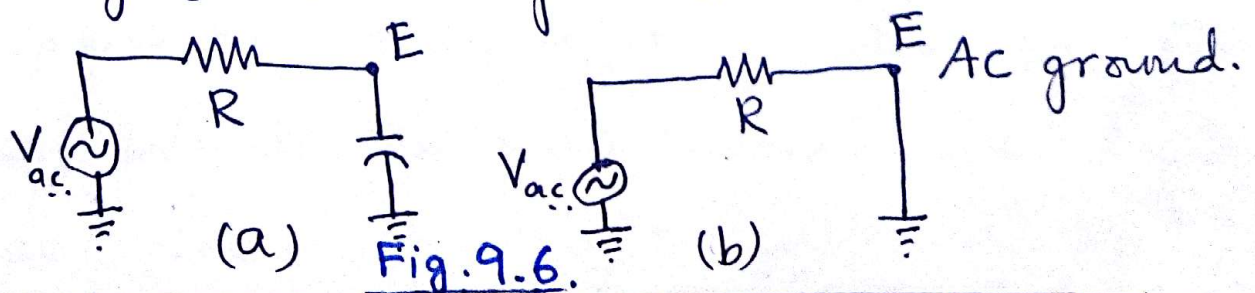


§ 9.2. Emitter-Biased Amplifier.

The base-biased amplifier has an unstable Q point. For this reason, it is not used much as an amplifier. Instead, an emitter-biased amplifier (either VDB or TSEB) with its stable Q point is preferred.
 (Two supply Emitter Bkgs)

§§. Bypass Capacitor:- Bypass Capacitor is similar to a coupling capacitor because it appears open to direct current and shorted to alternating current. But it is not used to couple a signal between two points. Instead, it is used to create an ac ground.

Fig. 9.6(a) shows an ac voltage source connected to a resistor and a capacitor. When the frequency is high enough the capacitive reactance is much smaller than the resistance. In this case, almost all the ac source voltage appears across the resistor, i.e., point E is effectively shorted to ground.



When used in this way, the capacitor is called a bypass capacitor because it bypasses or shorts point E to ground. A bypass capacitor is important because it allows us to create an ac ground in an amplifier without disturbing its Q-point.

For a bypass capacitor to work properly its reactance must be much smaller than the resistance at the lowest frequency of the ac source. For a good bypass,

$$X_c < 0.1 R$$

When this rule is satisfied, Fig. 9.6(a) can be replaced by the equivalent circuit of Fig. 9.6(b).

§§ VDB Amplifier. Fig. 9.7 shows a voltage divider-biased (VDB) amplifier. To calculate the dc voltage and currents, mentally open all capacitors. Then, the transistor circuit simplifies to the VDB circuit. The quiescent or dc values for this circuit are:

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$$V_B = 1.8V \text{ as } (V_B = V_{CC} - I_B R_1 = 10 - 0.819 \times 10^{-3} \times 10 \times 10^3 \Omega)$$

$$= (10 - 8.19 \times 10^{-4} \times 10^3)$$

$$V_E = 1.1V \text{ as } (V_E = V_B - V_{BE} = 1.8 - 0.7 = 1.1V)$$

$$V_C = 6.04V \text{ as } (V_C = V_{CC} - I_C R_C = 10 - 1.1 \times 10^{-3} \times 3.6 \times 10^3 = 6.4V)$$

$$I_C = 1.1mA \text{ as } (I_E = \frac{V_E}{R_E} = \frac{1.1}{1K\Omega} = 1.1mA)$$

As shown in Fig. 9.7 coupling capacitor is used between the source and base, and another coupling capacitor between the collector and the load resistance.

A bypass capacitor is also used between the emitter and ground. Without this capacitor, the ac base current would be much smaller. But with the bypass capacitor, a much larger voltage gain.

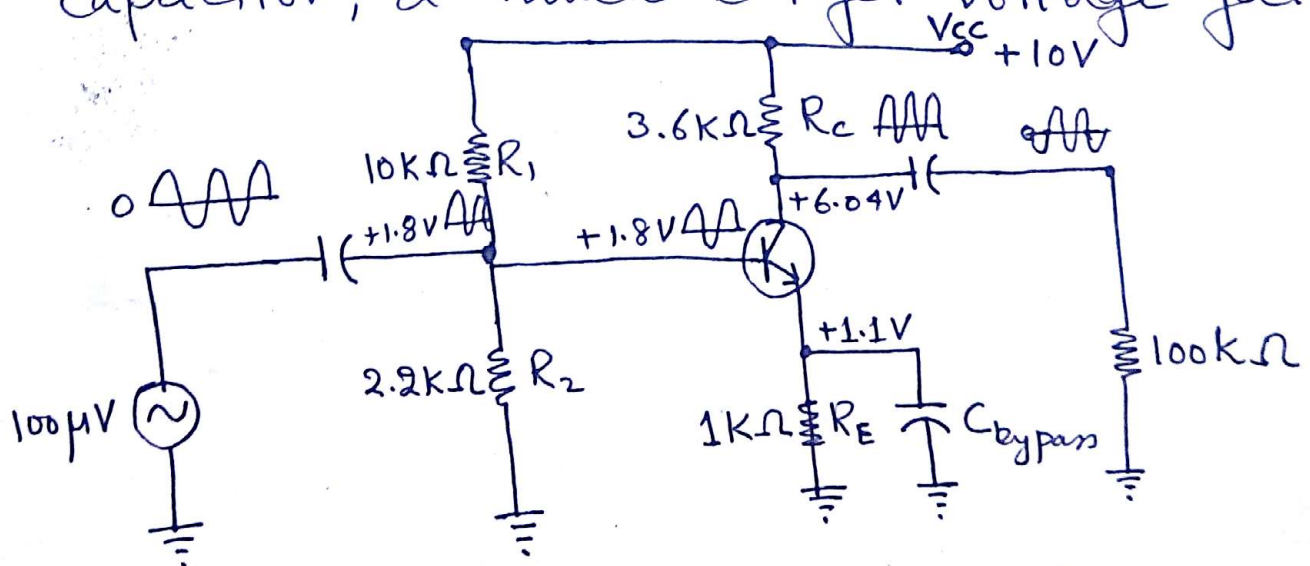


Fig. 9.7: VDB Amplifier with waveforms.

The ac source voltage is 100µV. This is coupled into the base. Because of the bypass capacitor all of this ac voltage appears across the base-emitter diode. The ac base current then produces an amplified ac collector voltage.

The dc current gain is defined by the relation

$$\beta_{dc} = \frac{I_c}{I_b}$$

The dc current gain depends upon the location of the Q-point.

The ac current gain is defined as:

$$\beta = \frac{i_c}{i_b} = h_{fe}$$

The value of β depends on the value of dc collector current.

On data sheets, β_{dc} is listed as h_{FE} and β as h_{fe} . The two current gains are comparable in value hence any of the ratios can be used.

§ 9.5. AC resistance of the emitter Diode.

The ac resistance of the emitter diode equals the ac base-emitter voltage divided by the ac emitter current;

$$r'_e = \frac{V_{be}}{i_e}$$

The prime (') in r'_e is a standard way to indicate that the resistance is inside

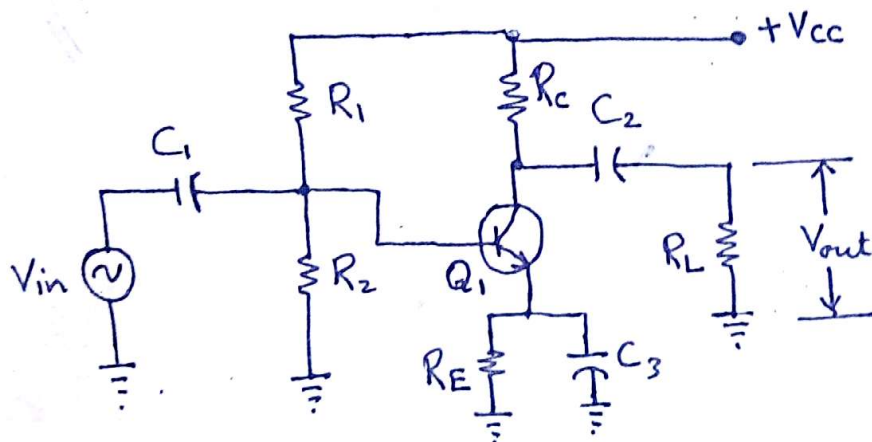
the transistor. For instance, an ac base-emitter

See Examples 9.1, 9.2, 9.3 from the Book voltage of 5 mV pp sets up an ac emitter current of 100 μ A pp, then the ac resistance of the emitter diode is $r'_e = \frac{5 \text{ mV}}{100 \mu\text{A}} = 50 \Omega$ at a given Q-point.

★ A remarkable for emitter resistance is $r'_e = \frac{25 \text{ mV}}{I_E}$

Voltage Amplifiers.

§ 10.1 :- Voltage Gain. Fig 10.1 a shows a voltage-divider-biased (VDB) amplifier.



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Fig 10.1(a). Voltage-divider-biased (VDB)

the voltage gain was defined as the ac output voltage divided by the ac input voltage. With this definition we can derive another equation for voltage gain.

§§ Derived from The π Model. Fig. 10.1b shows the ac equivalent circuit using π model of the transistor. The ac base current i_b flows through the input impedance of the base (βr_e).

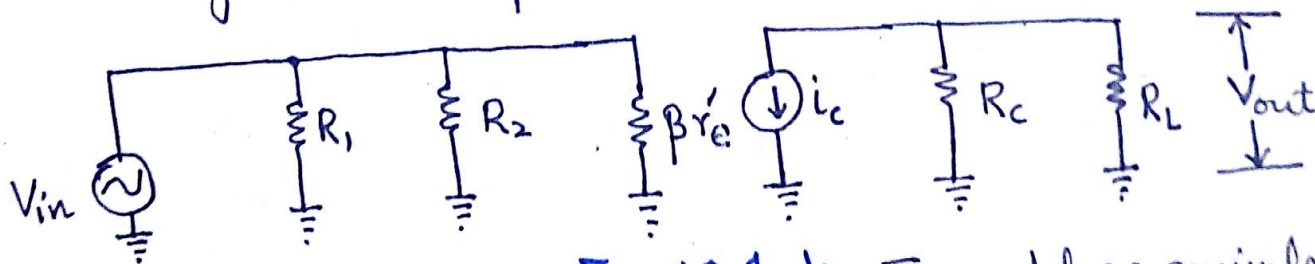


Fig. 10.1.b. π -model ac equivalent circuit

With Ohm's Law, we can write

$$V_{in} = i_b \beta r_e \quad \text{--- (i)}$$

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In the collector circuit, the current source pumps an ac current i_c through the parallel connection of R_c and R_L . Therefore, the ac output voltage is,

$$V_{out} = i_c (R_c \parallel R_L) \\ = \beta i_b (R_c \parallel R_L) \quad \text{---(ii)}$$

Hence, the voltage gain can be written as,

$$A = \frac{V_{out}}{V_{in}} = \frac{\beta i_b (R_c \parallel R_L)}{i_b \beta r_e'} \\ \text{or} \quad A = \frac{(R_c \parallel R_L)}{r_e'} \quad \text{---(iii)}$$

Where r_e' is the ac resistance of the emitter diode defined as

$$r_e' = \frac{V_{be}}{i_e} \quad \text{---(iv)}$$

with $V_{be} = 25\text{mV} \sim 50\text{mV}$. or $r_e' = \frac{25\text{mV}}{I_e}$ (Approx.).
The prime (') in r_e' is a standard way to indicate that the resistance is inside the transistor.

§§ AC Collector Resistance. In Fig. 10.1.b, the total ac load resistance seen by the collector is the parallel combination of R_c and R_L . This total resistance is called the ac collector resistance, r_c , i.e.,

$$r_c = R_c \parallel R_L \quad \text{---(v)}$$

Hence the Eqn. for voltage gain, as defined by Eqn. (iii) can be written as

$$A = \frac{r_c}{r_e'} \quad \text{---(vi)}$$

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§10.3. Multistage Amplifiers.

To get more voltage gain, we can cascade two or more amplifier stages. This means using the output of the first stage as the input to a second stage. In turn, the output of the second stage can be used as the input of the third stage, and so on.

§§ Voltage Gain of The First Stage.

Fig 10.2, a shows a two stage amplifier.

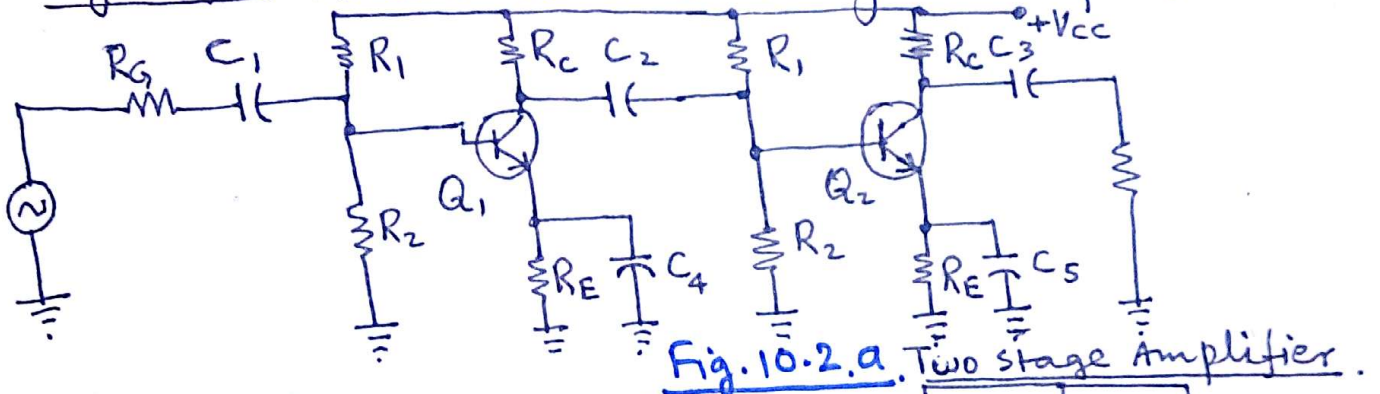


Fig. 10.2.a. Two stage Amplifier.

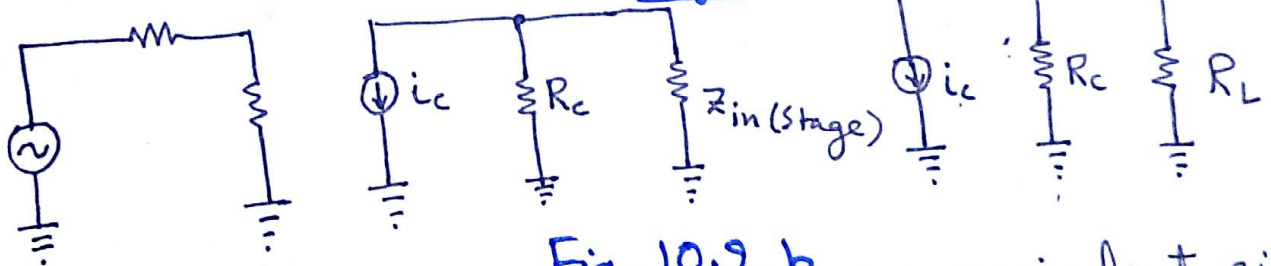


Fig. 10.2.b. ac equivalent circuit

The amplified and inverted signal out of the first stage is coupled to the base of the second stage. The amplified and inverted output of the second stage is then coupled to the load resistance. The signal across the load resistance is in phase with the generator signal. The two stages invert the signal by 360° equivalent to 0° (in phase).

§§ Voltage gain of the first stage :- Fig 10.2.b shows the ac equivalent circuit of the two stage amplifier. Note that the input impedance of the second stage loads down the first stage, i.e., Z_{in} of the second stage is in parallel with the R_c of the first stage. The ac collector resistance of the first stage is:

$$r_c = R_c \parallel Z_{in(stage)} \quad \text{---(i)}$$

The voltage gain of the first stage is:

$$A_1 = \frac{R_c \parallel Z_{in(stage)}}{r_e'} \quad \text{---(ii)}$$

§§ Voltage gain of the second stage. r_e'

The ac collector resistance of the second stage is:

$$r_c = R_c \parallel R_L \quad \text{---(iii)}$$

and the voltage gain is:

$$A_2 = \frac{R_c \parallel R_L}{r_e'} \quad \text{---(iv)}$$

§§ Total Voltage Gain. The overall voltage gain of the amplifier is given by the product of the individual gains:

$$A = A_1 A_2 \quad \text{---(V)}$$

For instance if each stage has a voltage gain of 50, The overall voltage gain is $A = 50 \times 50 = 2500$.

§ 11.1 Classes of Operation.

§§ Class A Operation :- Class A operation of an amplifier means that the transistor operates in the active region at all times. This implies that collector current flows for 360° of the ac cycle as shown in Fig. 1 (a)

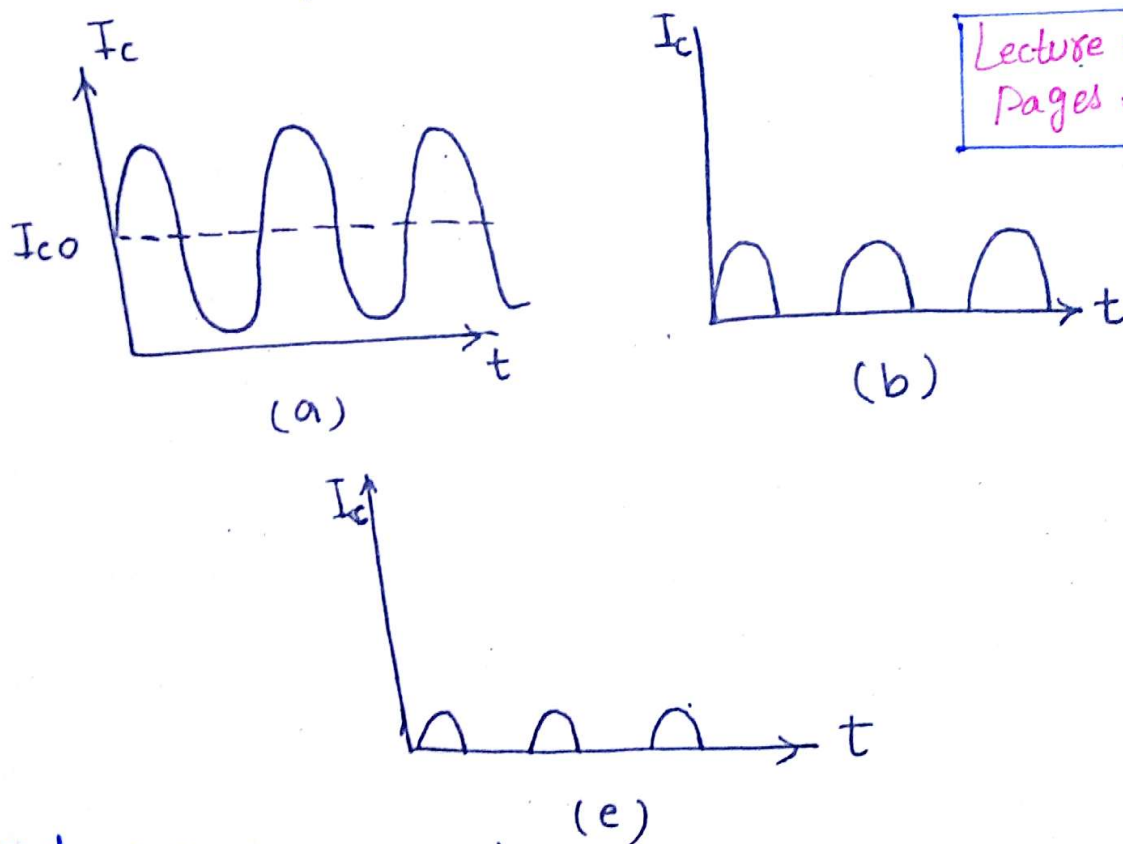


Fig. 1. Collector current (a) Class A; (b) Class B; (c) Class C.

With a class A amplifier, the designer usually tries to locate the Q-point somewhere near the middle of the load line. This way, the signal can swing over the maximum possible range without saturating or cutting off the transistor, which would distort the signal.

§§ Class B operation.

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Class B operation of an amplifier means that the Transistor operates (the collector current flows) for only half the cycle (180°), as shown in Fig. 1.b.

To have this kind of operation, a designer locates the Q point at cutoff. Then only the positive half of ac base voltage can produce collector current. This reduces the wasted heat in power transistors.

§§ Class C operation. Class C operation means that collector current flows for less than 180° of the ac cycle, as shown in Fig. 1.c.

With class C operation, only part of the positive half cycle of ac base voltage produces collector current. As a result, we get brief pulses of collector current.

§§ Types of Coupling. Fig. 2.a shows capacitive coupling. The coupling capacitor transmits the amplified ac voltage to the next stage. Fig. 2.b illustrates transformer coupling. Here the ac is coupled through a transformer to the next stage. Capacitive coupling and

transformer coupling are both examples of ac coupling, which blocks the dc voltage.

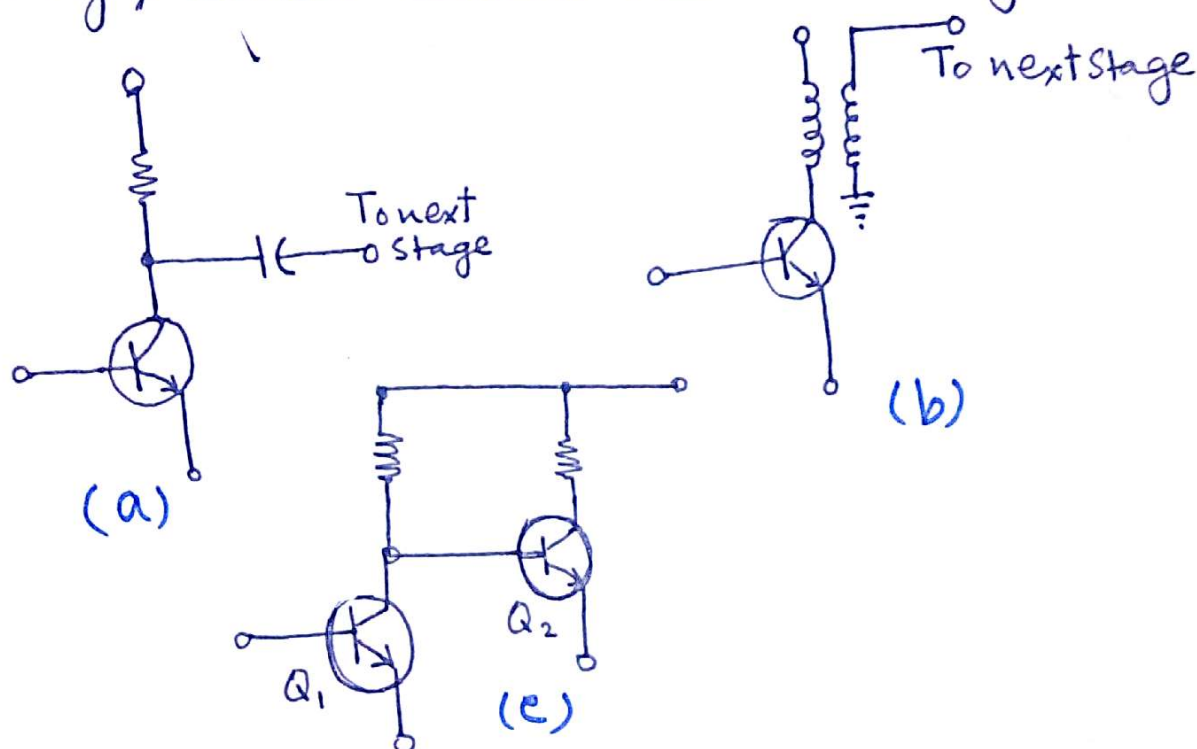


Fig. 2. Types of coupling (a) Capacitive (b) Transformer (c) Direct

Direct coupling is different. In Fig 2.c There is a direct connection between the collector of the first transistor and the base of the second transistor. Because of this, both the dc and the ac voltages are coupled. Since there is no lower frequency limit, a direct-coupling amplifier is sometimes called a dc amplifier.

Frequency An other way to describe amplifiers is by stating their frequency range. For instance, an audio amplifier operates in the range of 20 Hz to 20 KHz. A radio frequency (RF) range is above 20 KHz, usually much higher.

The VDB amplifier in Fig. 3 (a) is a class A amplifier as long as the output signal is not coupled. With this kind of amplifier, collector current flows throughout the cycle.

§§ Power Gain:- Besides voltage gain, any amplifier has a power gain, defined as

$$G = \frac{P_{out}}{P_{in}} \quad \text{--- (i)}$$

The power gain equals the ac output power divided by the ac input power.

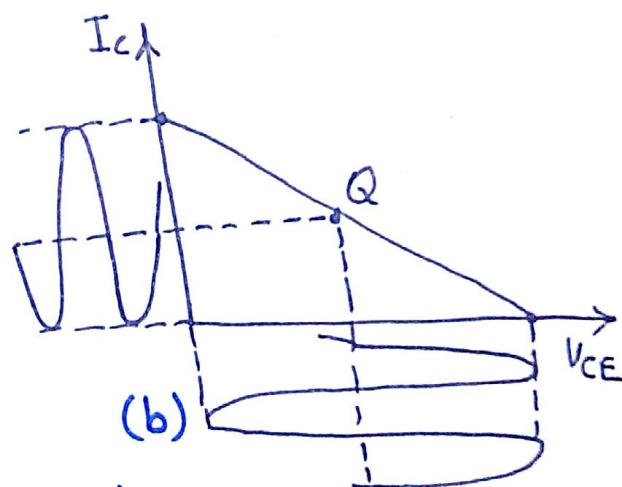
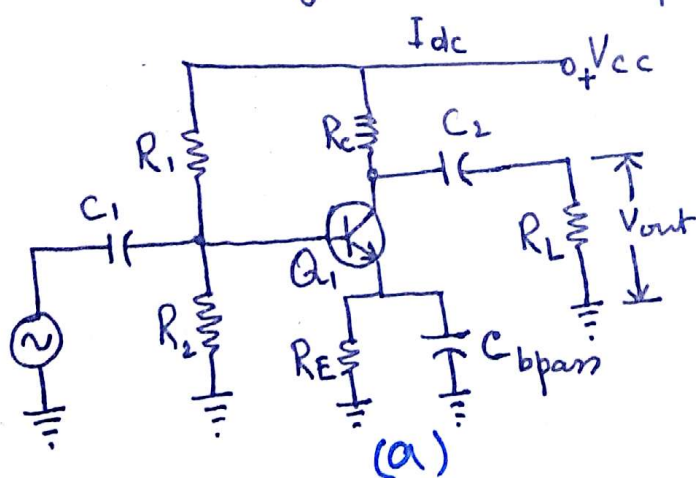


Fig. 3. Class A amplifier a) circuit (b) wave amplified

For instance, if the amplifier of Fig. 3 has an output power of 10 mW and an input power of 10 μ W, it has a power gain of

$$G = \frac{10 \text{ mW}}{10 \mu \text{ W}} = 1000$$

or

$$G = 1000.$$

§§ Output Power.

If we measure the output voltage of Fig.3 in rms volts, the output power is given by;

$$P_{out} = \frac{V_{rms}^2}{R_L} \quad \text{---(ii)}$$

Usually, The output voltage is measured in peak-to-peak volts with an oscilloscope. In this case, a more convenient equation to use for output

power is:

$$P_{out} = \frac{V_{out}^2}{8 R_L} \quad \text{---(iii)}$$

The factor 8 in the denominator occurs because

$$V_{pp} = 2\sqrt{2} V_{rms}.$$

The maximum output power occurs when the amplifier is producing the maximum peak-to-peak output voltage, as shown in Fig.3.b.

In this case, V_{pp} equals the maximum peak-to-peak output voltage and the maximum output power is

$$P_{out(max)} = \frac{V_{MPP}^2}{8 R_L} \quad \text{---(iv)}$$

§§ Transistor Power Dissipation:- When no signal drives the amplifier of Fig.3.a the quiescent power dissipation is:

$$P_{DQ} = V_{CEQ} I_{CQ} \quad \text{---(v)}$$

When a signal is present, the power dissipation of a transistor decreases because some power is converted to signal power.

§§ Efficiency. The efficiency of any amplifier is from 0 to 100 defined by $\eta = \frac{P_{out}}{P_{dc}} \times 100\%$

§§ Push-Pull Circuit:- Fig 4 shows a basic class B amplifier.

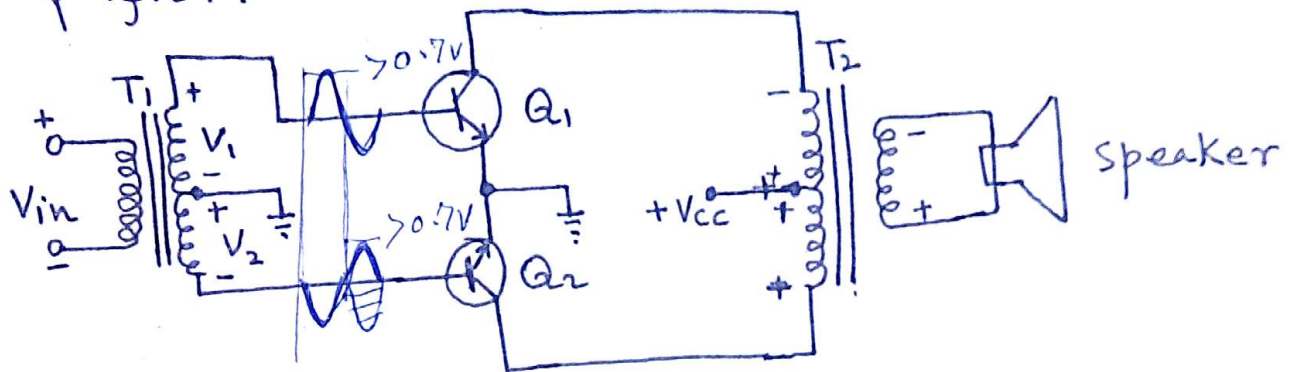


Fig.4. Class B push-pull amplifier.

When a transistor operates as class B amplifier, it clips off half a cycle. To avoid the resulting distortion, we can use two transistors in a push-pull arrangement like that of Fig.4.

Push-pull means that one transistor conducts for half a cycle while the other is off, and vice versa.

On the positive half cycle of the input voltage, the secondary winding of T_1 has voltage V_1 and V_2 , as shown in Fig.4. Therefore upper transistor conducts and the lower one cuts off. The collector current through Q_1 flows. On the next half cycle of the input voltage the polarities reverse. Now the lower transistor turns on and the upper transistor turns off. The lower transistor amplifies the signal. Since each transistor amplifies one half of the input signal, the loudspeaker receives complete amplified signal.

§§ 17.1. The Differential Amplifier.

① Transistors, diodes and resistors are the only practical components in typical ICs. Capacitors may also be used but they are small, usually less than 50pF. For this reason, IC designers cannot use coupling and bypass capacitors the way a discrete circuit designer can, the IC designer has to use direct coupling between stages.

The differential amplifier (diff. amp) is the key. The design of this circuit is extremely clever because it eliminates the need for an emitter bypass capacitor. For this and other reasons, the diff. amp. is used as the input stage of almost every IC op amp.

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§§ Differential input and output.

Fig. 17.1 shows a diff. amp. It is two CE stages in parallel with a common emitter resistor.

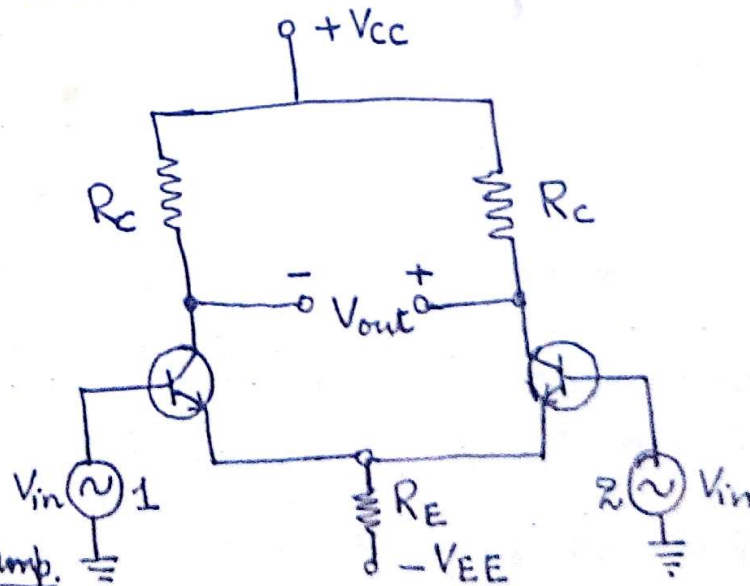


Fig. 17.1. Diff. amp.

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Although it has two input voltages (V_1 and V_2) and two collector voltages (V_{C1} and V_{C2}), the overall circuit is considered to be one stage. Because there is no coupling or bypass capacitor, there is no lower cutoff frequency.

The ac output voltage V_{out} is defined as the voltage between the collectors with the polarity shown in Fig. 17.1.

$$V_{out} = V_{C2} - V_{C1} \quad \text{--- (i)}$$

This voltage is called a differential output because it combines the two ac collector voltages into one voltage that equals the difference of the collector voltages.

Ideally, the circuit has identical transistors and equal collector resistors. With perfect symmetry, V_{out} is zero when the two input voltages are equal. When V_1 is greater than V_2 , the output voltage has the polarity shown in Fig. When V_2 is greater than V_1 , the output voltage is inverted and has the opposite polarity. The diff. amp. of Fig. 17.1 has two separate inputs. Input V_1 is called the non-inverting input because V_{out} is in phase with V_1 .

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where V_2 is called the inverting input because V_{out} is 180° out of phase with V_2 . In some applications only the noninverting input is used and the inverting input is grounded. In other applications only the inverting input is active and the noninverting input is grounded.

When both the inverting and noninverting input voltages are present, the total input is called a differential input because the output voltage equals the voltage gain times the difference of the two input voltages. The equation for the output voltage is:

$$V_{out} = A(V_1 - V_2) \text{ --- (ii)}$$

Where A is the voltage gain.

For non-inverting configuration $V_2 = 0$, hence

$$V_{out} = AV_1 \text{ --- (iii)}$$

In some applications, V_2 is the active input and V_1 is grounded input, In this case Eqn. (ii) gives,

$$V_{out} = -AV_2 \text{ --- (iv)}$$

The minus sign in Eqn. (iv) indicates phase inversion

a double ended output.

Fig. 18.2 (a) is the schematic symbol of an op amp.

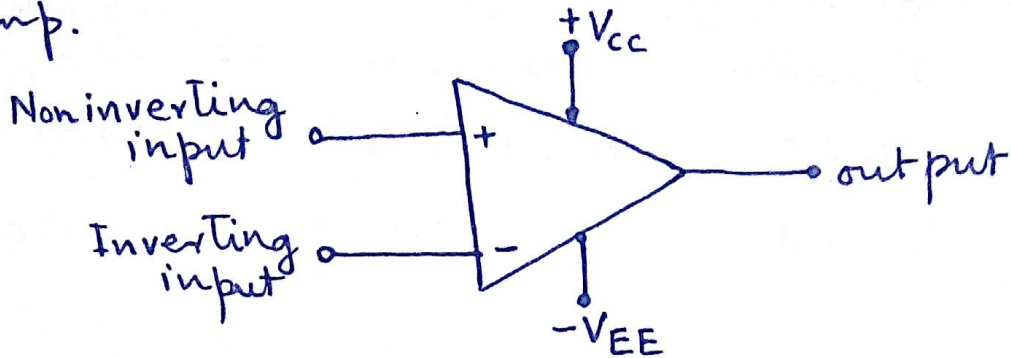


Fig. 18.2.a. Schematic symbol for op amp.

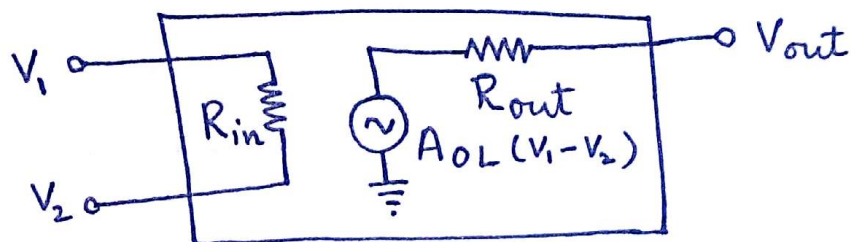


Fig. 18.2.b. Equivalent circuit of op amp.

It has noninverting and inverting inputs and a single ended output. Ideally this symbol means that amplifier has infinite voltage gain, infinite input impedance and zero output impedance. The ideal op amp represents a perfect voltage amplifier and is often referred to as a voltage-controlled voltage source (VCVS), where R_{in} is infinite and R_{out} is zero. The ideal op amp has infinite voltage gain and infinite unity-gain frequency.

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LM741C is a standard op amp, a classic that has been available since the 1960s. Its characteristics are the minimum of what to expect from a monolithic op amp. The LM741C has a voltage gain of 100,000, a unity-gain frequency of 1MHz, an input impedance of $2M\Omega$ and so on. Because the voltage gain is so high, the input offsets can easily saturate the op amp. This is why practical circuits need external components between the input and the output of an op amp to stabilize the voltage gain. For instance, in many applications negative feedback is used to adjust the overall voltage gain to much lower value in exchange for stable linear operation.

Table 18.1. Typical Op-Amp characteristics

Quantity	Symbol	Ideal	LM741C	LF157A
Open loop voltage gain	A_{OL}	infinite	100,000	200,000
Unity gain frequency	f_{unity}	infinite	1MHz	20MHz
Input resistance	R_{in}	infinite	$2M\Omega$	$10^{12}\Omega$
Output resistance	R_{out}	zero	75Ω	100Ω
Input base current	$I_{in(base)}$	zero	80nA	30pA
Input offset current	$I_{in(off)}$	zero	20nA	3pA
Input offset voltage	$V_{in(off)}$	zero	2mV	1mV
Common mode rejection ratio	CMRR	infinite	90dB	100dB

§ 18.2. Characteristics of Op-Amp.

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An op-amp has a large number of characteristics, we will discuss only three of them.

i) Input resistance:- It is the resistance between the (+) and (-) inputs of the amplifier as shown in Fig. 18.3.

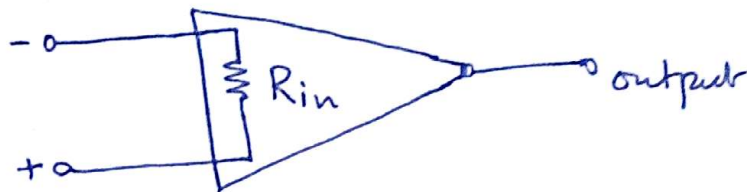


Fig. 18.3. Input resistance of an op-amp

Its value is very high, of the order of several megaohms. Due to high value of input resistance R_{in} practically no current flows between the two input terminals.

ii) Output resistance:- It is the resistance between the output terminal and the ground. Its value is only few ohms. Fig. 18.4

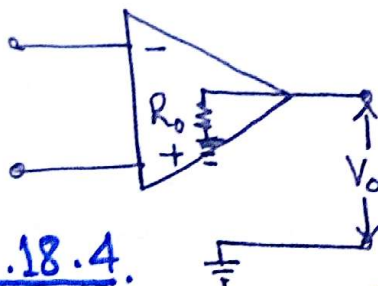


Fig. 18.4.

iii) Open Loop Gain. It is the ratio of the output voltage V_o to the voltage difference between non-inverting and inverting inputs, when there is no external connection between the output and the input, i.e.,

$$A_{OL} = \frac{V_o}{V_+ - V_-} = \frac{V_o}{V_i} \approx 100,000 \quad (i)$$

§§ Op-Amp as inverting amplifier.

Fig. 18.5. shows the circuit of an op-amp when used as an inverting amplifier.

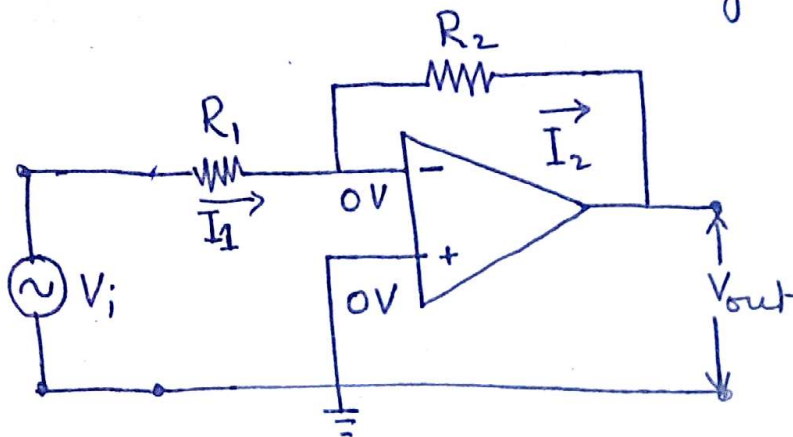


Fig. 18.5. Op-amp as inverting amplifier.

The input signal V_i which is to be amplified is applied at the inverting terminal (-) through a resistance R_1 . The non-inverting terminal (+) is grounded i.e. its potential is zero. We know that A_{OL} is very high of the order of 10^5 so according to Eqn (i) for any value of V_o , $V_+ - V_- \approx 0$ or $V_+ \approx V_-$. Since V_+ is at ground so V_- is Virtually at ground potential, i.e., $V_- \approx 0$. Referring to Fig. 5

$$\text{Current through } R_1 = I_1 = \frac{V_i - V_-}{R_1} = \frac{V_i - 0}{R_1} = \frac{V_i}{R_1}$$

$$\text{Current through } R_2 = I_2 = \frac{V_- - V_o}{R_2} = -\frac{V_o}{R_2}$$

As practically no current flows between (-) and (+) terminals, so according to

Kirchhoff's current rule $I_1 = I_2$

or
$$\frac{V_i}{R_1} = -\frac{V_o}{R_2}$$

or
$$\frac{V_o}{V_i} = -\frac{R_2}{R_1}$$

As V_o/V_i is defined as gain G of the inverting amplifier, so $G = -\frac{R_2}{R_1}$ ——— (ii)

The negative sign indicates that the output signal is 180° out of phase with respect to the input signal. It is interesting to note that the close loop gain depends upon the two externally connected resistance R_1 and R_2 . The gain is independent of what is happening inside the amplifier.

If $R_1 = 10 \text{ k}\Omega$ and $R_2 = 100 \text{ k}\Omega$, the gain of the amplifier is $G = \frac{-100 \text{ k}\Omega}{10 \text{ k}\Omega} = -10$.

§§ Op-amp as Non-inverting Amplifier.

The circuit diagram of op-amp as non-inverting amplifier is shown in Fig 18.6.

In this case the input signal V_i is applied at the non inverting terminal (+). Due to high open loop gain of amplifier, the inverting (-)

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and non-inverting (+) inputs are virtually at the same potential, i.e.,

$$V_- \approx V_+ \approx V_i$$

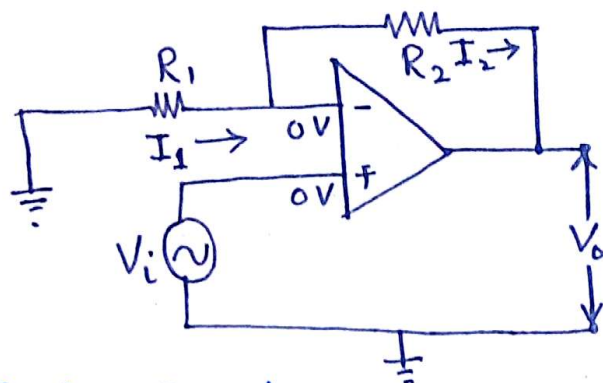


Fig. 18.6. Op-Amp as non inverting amplifier.

Also from Fig. 18.6,

$$\text{current through } R_1 = I_1 = \frac{0 - V_-}{R_1} = \frac{0 - V_i}{R_1} = -\frac{V_i}{R_1}$$

$$\times \text{ current through } R_2 = I_2 = \frac{V_- - V_o}{R_2} = \frac{V_i - V_o}{R_2}$$

As practically no current flows between (-) and (+) terminals, so by Kirchhoff's current rule $I_1 = I_2$ or

$$-\frac{V_i}{R_1} = \frac{V_i - V_o}{R_2}$$

$$\text{or } V_i \left[\frac{1}{R_1} + \frac{1}{R_2} \right] = \frac{V_o}{R_2}$$

$$\text{or } \text{Gain} = \frac{V_o}{V_i} = 1 + \frac{R_2}{R_1} \text{ ————— (iii)}$$

Again, the gain of the amplifier is independent of the internal structure of the op-amp. It just depends upon the externally connected resistance R_1 & R_2 . The positive sign indicates that the input & output signals are in phase.

Oscillators

§ Feedback Theory:- A simple analogue feedback control circuit can be constructed using individual or discrete components, such as transistors, resistors, capacitors etc. or by using integrated circuit (IC's) to form complex digital feedback system

A feedback system is one in which The output signal is sampled and then fed back to The input. There are two main types of feedback control namely:

Positive feedback and Negative feedback.

§§ Positive feedback:- In a positive feedback control system, The setpoint and output values are added together by The controller as The feedback is "in-phase" with The input. The effect of positive (or regenerative) feedback is to increase The system gain, i.e., The overall gain with positive feedback applied will be greater than The gain without feedback. Regenerative or positive feedback is one of the requirements to sustain oscillations in an oscillator.

An example of a positive feedback system could be an operational amplifier with R_F looped to the non-inverting input as shown in Fig. 1

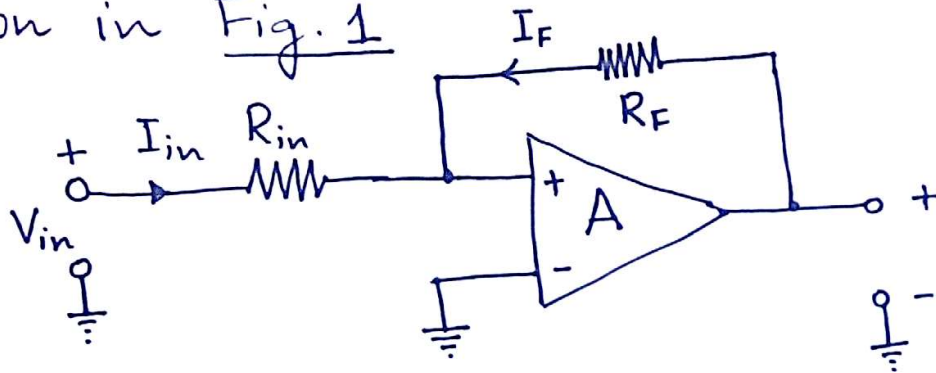


Fig. 1. Positive feedback

Thus The input voltage becomes more positive, causing an even larger output voltage and so on. Eventually The output becomes saturated at its positive supply rail.

§§ Negative Feedback System:- In a negative feedback control system, The set point and The output values are subtracted from each other as The feedback is "out-of-phase" with The original input. The effect of negative (or degenerative) feedback is to "reduce" The gain. Because negative feedback produces stable circuit response, improves stability and increases The operating bandwidth of a given system, The majority of all control and feedback systems is

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degenerative reducing the effects of the gain.
An example of negative feedback system is an electronic amplifier based on an operational amplifier as shown in Fig. 2.

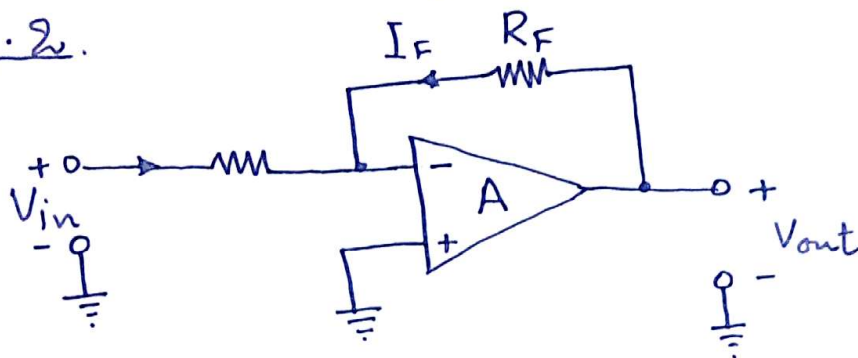


Fig. 2. Negative feedback System.

Negative feedback control of the amplifier is achieved by applying a small part of the output voltage signal at V_{out} to the inverting (-) input terminal via the feedback resistor, R_f . Thus the input voltage is reduced by the negative feedback signal, causing an even smaller output voltage and so on. Eventually the output will settle down and become stabilised at a value determined by the gain ratio of R_f/R_{in} . The use of negative (-) feedback in amplifier and process control system is widespread since it is more stable than positive feedback systems.

§ Oscillators

§§ Introduction:- Any unit which is used to generate a.c. voltage at the output without an input a.c. signal is called an oscillator. Its key application is in the communication system designing. Oscillators are also used to generate radio frequency signals. They are also called signal generators. In a way, we can say that the function of an oscillator is reverse of a rectifier, since generally oscillators are supposed to provide a.c. voltage signals. The output signals are of desired frequency. Oscillators can be classified into two main types;

1. Sine wave oscillators.
2. Relaxation oscillators.

1. Sinusoidal or Harmonic Oscillators.

:- Sine wave or harmonic oscillators are which produce output having sine or cosine nature. They produce waveform in the frequency range from 20 Hz to 1 GHz.

2. Non-Sinusoidal or Relaxation Oscillators.

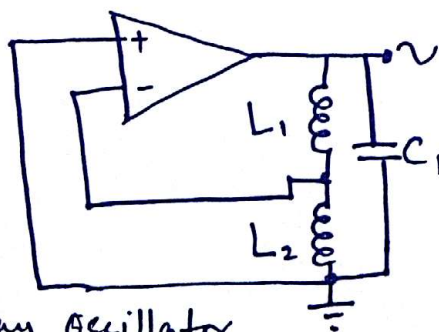
:- The oscillators which provide an output having a square, rectangular or sawtooth wave form are called non-sinusoidal or relaxation oscillators. Such oscillators can provide output at frequencies ranging from zero to 20 MHz.

§§ Types of Sinusoidal or harmonic Oscillators

:- Sinusoidal oscillators can be further subdivided into following types;

1. Tuned Circuit Oscillators.

:- These oscillators use a tuned-circuit consisting of inductor (L) and capacitor (C) and are used to generate high frequency signals. Thus They are also known as radio frequency (RF) oscillators or LC-oscillators (Tank circuit). Such oscillators are Hartley and Colpitts oscillators etc.

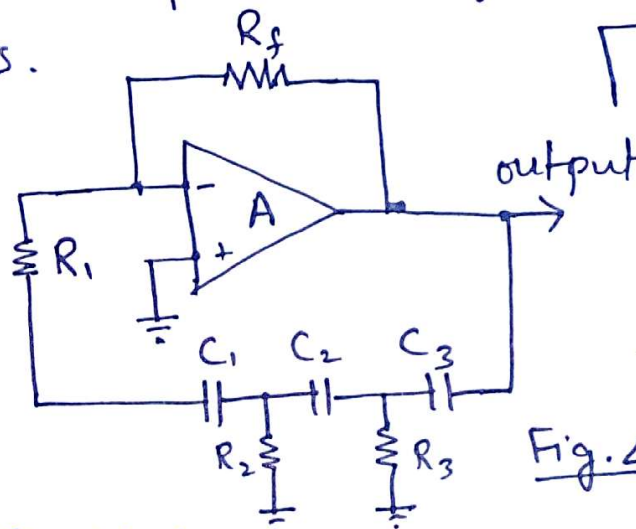


Hartley Oscillator

Fig. 3. - The circuit was invented in 1915 by American engineer Ralph Hartley.

2. RC Oscillators :-

:- These oscillators use resistors and capacitors and are used to generate low or audio frequency signals. They are also known as audio-frequency oscillators (A.F.). Such oscillators are phase shift and wien-bridge oscillators.



Criterion

$$R_f = 29 \cdot R$$

for $R_1 = R_2 = R_3 = R$
& $C_1 = C_2 = C_3 = C$

$$f_{\text{oscillation}} = \frac{1}{2\pi RC\sqrt{6}}$$

Fig. 4 :- Phase-Shift Oscillator.

3. Crystal Oscillators.

:- These oscillators use quartz crystal and are used to generate highly stabilized output signals with frequencies up to 10 MHz. The pierce oscillator is an example of crystal oscillator.

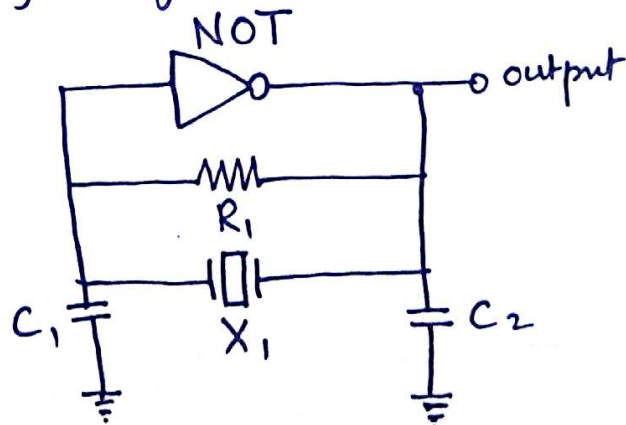


Fig. 5 :- Piezoelectric Crystal (Pierce) Oscillator

4. Negative Resistance Oscillators.

:- These oscillators use negative resistance characteristics of the devices such as tunnel diodes. A tuned diode oscillator is an example of negative resistance oscillator.

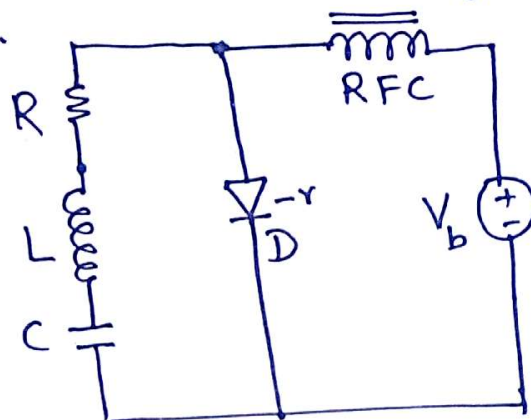


Fig. 6:- A Negative resistance oscillator.

§. Factors Affecting The stability of Oscillator.

:- The frequency stability of an oscillator is a measure of its ability to maintain frequency, over a long time interval. The factors affecting the stability of an oscillator are operating point, circuit components, supply voltage, output load, inter element capacitances and stray capacitances. The effect of change in inter element capacitances can be neutralized by putting an additional capacitor across the corresponding element. However, it is difficult to avoid the effect of stray capacitance.